Understanding and Addressing Food Loss and Waste:

A Multidimensional Analysis of Wheat Loss and Bread Waste in

Iran

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"Here with a Loaf of Bread beneath the Bough,

A Flask of Wine, a Book of Verse – and Thou

Beside me singing in the Wilderness –

And Wilderness is Paradise enow."

Omar Khayyám, Rubaiyat of Omar Khayyam

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Summary

Food loss and waste (FLW) is a pressing global issue that poses significant environmental and economic consequences while threatening food security. Recent reports indicate that food loss, occurring along the production and supply chains from farm to retail (excluding the retail stage), accounts for 14% of global food production, while food waste, the discarding of food at the consumption stage, amounts to 17% of globally produced food. Despite this alarming data, there are substantial data gaps and a lack of knowledge concerning the extent and causes of FLW, particularly in developing countries. Among developing countries, Iran, in particular, faces significant challenges in meeting the food demand of its growing population due to extensive international sanctions, alongside environmental and agricultural difficulties, such as water scarcity.

Considering the urgency of addressing FLW for sustaining food security in Iran, the primary aim of this doctoral study was to comprehensively investigate FLW in Iran, adopting a lifecycle approach with a focal focus on the major loss and waste hotspots (LWH). Recognizing the significance of bread as the country's main staple, the study focused on wheat and wheat bread. Taking into consideration the significant role of Fars province as a major wheat-producing region in Iran, this province was chosen as the target location for this research. The study concentrated on quantifying food waste and analyzing its associated factors at the consumption stage within Shiraz, which is the capital and the largest city of the province. The study encompassed several research objectives, including (1) mapping the wheat lifecycle, with a specific focus on wheat bread as the final product, (2) identifying LWH, (3) enhancing the precision of FLW quantification methods, (4) measuring wheat and bread loss and waste and evaluating the reliability of existing data, (5) investigating the underlying causes and associated factors; and exploring potential solutions, such as policy interventions, to mitigate wheat loss and bread waste. Data collection for this study involved the implementation of two surveys and a laboratory experiment.

The first survey, conducted in October 2018 through 14 expert interviews, utilized the value stream mapping (VSM) methodology to map the entire wheat and bread lifecycle (WBL). Additionally, open-ended questions were employed during the interviews to identify specific LWH. The first article within this cumulative dissertation presents a comprehensive cradle-to-grave overview of the WBL. The study highlights farms, foodservice establishments, and households as the major LWH. Furthermore, the research revealed significant data gaps at both the farm and household levels. The second article focuses on examining the underlying causes of on-farm wheat loss, utilizing a subset of qualitative data obtained from the first survey. The research findings indicate that a significant amount of wheat loss occurs due to seed overuse, pest infestation, and improper harvesting practices. Moreover, this paper

explores potential approaches to address the issue and suggests empowering agricultural cooperatives through changes in government intervention in wheat production.

In response to the initial findings revealing a data gap in household bread waste, the second survey investigated household bread waste (HBW). From December 2018 to August 2019, 419 households in Shiraz were surveyed to quantify HBW and examine its links to households' dietary patterns and socioeconomic status. For this purpose, the individual responsible for the household's nutrition was interviewed using a questionnaire divided into three sections, including a self-assessment questionnaire to quantify HBW, a locally validated food frequency questionnaire to collect dietary data, and a third section focusing on socioeconomic status. The survey findings led to the publication of three articles within the dissertation.

The first article of the second survey, which is presented as the third article of the dissertation, focuses on addressing the underestimation error inherent in the self-assessment method employed. A lab experiment simulated common consumption recipes and measured resulting waste. Comparing the lab results with HBW estimates from the questionnaire survey, the article presents underestimation ratios ranging from 1.24 to 1.80. These ratios improved the accuracy of HBW estimates discussed in the fourth article of the dissertation. The fourth article reveals HBW in Shiraz at 1.80%, with traditional bread waste at 1.70% and non-traditional bread waste at 2.50%. However, these percentages do not consider the underestimation inherent in the self-assessment method. Adjusting for underestimation within this study population, traditional bread waste increases to 3.06%, and non-traditional bread waste rises to 3.58%. Additionally, the article highlights the unreliable nature of outdated data from previous Iranian reports and studies. The final article uses multiple regression modeling to predict HBW based on household dietary patterns and socioeconomic scores. It emphasizes the need for consumer-focused interventions to address household food waste effectively, such as developing FLW reduction policies targeting specific consumers grouped based on waste-related characteristics.

In conclusion, this cumulative dissertation offers a comprehensive analysis of wheat loss and bread waste in Iran, shedding light on its environmental, economic, and food security implications. The findings of this study offer valuable guidance for improving agricultural productivity, fostering farmers' governance and cooperation, and implementing consumer-focused food waste reduction strategies to promote sustainable consumption. This research contributes to methodological advancement in the field and provides insightful directions for future research. Furthermore, the study's outcomes provide essential information necessary for informed decision-making, enabling efforts to reduce wheat loss and bread waste and contribute to the establishment of a more responsible production and consumption system.

Zusammenfassung

Lebensmittelverluste und -abfälle sind ein drängendes globales Problem, das erhebliche ökologische und wirtschaftliche Folgen hat und die Ernährungssicherheit bedroht. Jüngsten Berichten zufolge werden 14 % der weltweit produzierten Lebensmittel durch Lebensmittelverluste entlang der Produktions- und Versorgungskette vom Landwirtschaftliche Betrieb bis zum Lebensmitteleinzelhandel (ohne Einzelhandel) vernichtet, und 17 % der weltweit produzierten Lebensmittel werden während des Verzehrs weggeworfen. Trotz dieser erschreckenden Daten gibt es erhebliche Datenlücken und einen Wissensmangel bezüglich des Volumens und der Ursachen von Lebensmittelverlusten und -abfällen, insbesondere in Entwicklungsländern. Unter den Entwicklungsländern steht vor allem der Iran vor großen Herausforderungen, wenn es darum geht, den Nahrungsmittelbedarf seiner wachsenden Bevölkerung zu decken, und zwar aufgrund umfangreicher internationaler Sanktionen sowie umwelt- und agrarpolitischer Probleme, wie z.B. Wasserknappheit.

In Anbetracht der Dringlichkeit, Lebensmittelverluste und -verschwendung zu bekämpfen, um die Lebensmittelsicherheit im Iran zu sichern, bestand das Hauptziel dieses Promotionsvorhabens darin, Lebensmittelverluste und -abfällen im Iran umfassend zu untersuchen, wobei ein Lebenszyklus-Ansatz mit Schwerpunkt auf den wichtigsten Verlust- und Abfallschwerpunkten verfolgt wurde. Da Brot das wichtigste Grundnahrungsmittel des Landes ist, konzentrierte sich die Studie auf Weizen und Weizenbrot. Wegen der bedeutenden Rolle der Provinz Fars als wichtige Weizenanbauregion im Iran wurde diese Provinz als Zielgebiet für diese Untersuchung ausgewählt. Die Studie konzentrierte sich auf die Quantifizierung von Lebensmittelabfällen und die Analyse der damit verknüpften Faktoren auf der Konsumstufe in Shiraz, der Hauptstadt und größten Stadt der Provinz. Die Studie umfasste mehrere Forschungsziele, darunter (1) die Abbildung des Lebenszyklus von Weizen mit besonderem Schwerpunkt auf Weizenbrot als Fertigerzeugnis, (2) die Identifizierung von Verlust- und Abfallschwerpunkten, (3) die Verbesserung der Genauigkeit von Methoden zur Quantifizierung von Lebensmittelverlusten und -abfällen, (4) die Messung von Weizen- und Brotverlusten und -abfällen und die Bewertung der Zuverlässigkeit vorhandener Daten, (5) die Untersuchung der zugrundeliegenden Ursachen und der damit zusammenhängenden Faktoren sowie die Erkundung potenzieller Lösungen, z. B. politischer Maßnahmen, zur Eindämmung von Weizenverlusten und Brotabfällen. Die Datenerhebung für diese Studie fand im Rahmen von zwei Umfragen und einem Laborexperiment statt.

Die erste Erhebung, durchgeführt im Oktober 2018 mit 14 Experteninterviews, verwendete die Wertflussanalyse, um den gesamten Lebenszyklus von Weizen und Brot abzubilden. Darüber hinaus wurden in den Interviews offene Fragen gestellt, um spezifische Verlust- und Abfallschwerpunkte zu ermitteln. Der erste Beitrag in dieser kumulativen Dissertation präsentiert einen umfassenden Überblick über den Lebenszyklus von Weizen und Brot von

der Wiege bis zur Bahre. Die Studie nennt landwirtschaftliche Betriebe, Gastronomiebetriebe und Haushalte als die größten Verlust- und Abfallschwerpunkte. Die Forschung ergab außerdem erhebliche Datenlücken sowohl auf der Ebene der landwirtschaftlichen Betrieb als auch der Haushalte. Der zweite Beitrag konzentriert sich auf die Untersuchung der Ursachen für die Weizenverluste in einem Landwirtschaftsbetrieb, wobei eine Teilmenge der qualitativen Daten aus der ersten Umfrage verwendet wird. Die Ergebnisse zeigen, dass ein Großteil der Weizenverluste auf übermäßige Verwendung von Saatgut, Pflanzenschädlinge und unsachgemäße Erntemethoden zurückzuführen ist. Weiterhin werden in diesem Beitrag mögliche Ansätze zur Lösung des Problems untersucht und vorgeschlagen, u.a. die landwirtschaftlichen Genossenschaften durch Änderungen der staatlichen Interventionen in der Weizenproduktion zu stärken.

Vor dem Hintergrund der Ergebnisse der ersten Umfrage, die eine Datenlücke bei den Brotabfällen in den Haushalten aufzeigte, wurden in der zweiten Umfrage die Brotabfälle in den Haushalten untersucht. Zwischen Dezember 2018 und August 2019 wurden 419 Haushalte in Shiraz befragt, um die Brotabfälle in den Haushalten zu quantifizieren und ihren Bezug zu den Ernährungsgewohnheiten und dem sozioökonomischen Status der Haushalte zu untersuchen. Dafür wurde die für die Ernährung des Haushalts verantwortliche Person anhand eines Fragebogens befragt, der in drei Abschnitte unterteilt war: einen Fragebogen zur Selbsteinschätzung, um die Brotabfälle im Haushalt zu quantifizieren, einen lokal validierten Lebensmittel Frequenz Fragebogen, um Daten zur Ernährung zu erheben, und einen dritten Abschnitt zum sozioökonomischen Status. Im Rahmen der Dissertation wurden drei Beiträge zu den Ergebnissen dieser Umfrage veröffentlicht.

Der erste Beitrag auf Grundlage der zweiten Umfrage, der als dritter Beitrag der Dissertation vorgelegt wird, befasst sich schwerpunktmäßig mit dem Unterschätzungsfehler der angewandten Selbsteinschätzungsmethode. In einem Laborexperiment wurden gängige Konsumrezepte simuliert und die daraus resultierenden Abfälle gemessen. Beim Vergleich der Laborergebnisse mit geschätzten Brotabfällen aus der Fragebogenerhebung werden in dem Beitrag Unterschätzungsquoten zwischen 1,24 und 1,80 angegeben. Diese Quoten verbesserten die Genauigkeit der Schätzungen für Brotabfälle in Haushalten, die im vierten Beitrag der Dissertation diskutiert werden. Der vierte Beitrag zeigt, dass in Shiraz 1,80 % der Brotabfälle in den Haushalten anfallen, wobei der Anteil der traditionellen Brotabfälle bei 1,70 % und der Anteil der nichttraditionellen Brotabfälle bei 2,50 % liegt. Allerdings berücksichtigen diese Zahlen die Unterschätzung nicht, die mit der Selbstbewertungsmethode einhergeht. Bei Berücksichtigung der Unterschätzung innerhalb dieser Studienstichprobe steigt der Anteil der traditionellen Brotabfälle auf 3,06 % und der Anteil der nicht-traditionellen Brotabfälle auf 3,58 %. Zusätzlich unterstreicht der Beitrag die Unzuverlässigkeit früherer iranischer Berichte und Studien, die auf veralteten Daten beruhen. Der letzte Beitrag verwendet ein multiples

Regressionsmodell, um Brotabfälle in Haushalten auf der Grundlage von Ernährungsgewohnheiten und sozioökonomischen Merkmalen zu prognostizieren. Die Studie verdeutlicht die Notwendigkeit verbraucherorientierter Maßnahmen, um die Lebensmittelabfälle in den Haushalten erfolgreich zu bekämpfen, z. B. durch die Entwicklung von Maßnahmen zur Verringerung von Lebensmittelabfällen, die sich an bestimmte Verbrauchergruppen richten, welche nach abfallbezogenen Merkmalen eingeteilt werden.

Abschließend bietet diese kumulative Dissertation eine umfassende Analyse der Weizenverluste und Brotabfälle im Iran und beleuchtet deren Auswirkungen auf die Umwelt, die Wirtschaft und die Ernährungssicherheit. Die Ergebnisse dieser Studie bieten wertvolle Anleitungen für die Verbesserung der landwirtschaftlichen Produktivität, die Förderung von Governance und Kooperation der Landwirte und die Umsetzung verbraucherorientierter Strategien zur Reduzierung von Lebensmittelabfällen, um nachhaltigen Konsum zu fördern. Diese Doktorarbeit trägt zu methodischen Fortschritten im Fachgebiet bei und bietet aufschlussreiche Hinweise für die künftige Forschung. Weiterhin liefern die Ergebnisse der Studie wichtige Informationen, die für eine fundierte Entscheidungsfindung notwendig sind und die es ermöglichen, Weizenverluste und Brotabfälle zu reduzieren und einen Beitrag zur Schaffung eines verantwortungsvollen Produktions- und Verbrauchssystems zu leisten.

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Chapter 1: General Introduction

1. Overview

The doctoral study presented in this dissertation is based on a research concept developed by the Food Security Center of the University of Hohenheim in Stuttgart, Germany, with the aim of investigating food loss and waste (FLW) in developing countries. The research concept was designed in response to the observed negative impacts of food waste on food security. Accordingly, the research project was initiated through a collaborative effort between the University of Hohenheim and three Iranian universities—Shahid Beheshti University of Medical Sciences in Tehran, Shiraz University of Medical Sciences, and Shiraz University in Shiraz.

The primary goal of this project was to conduct a comprehensive analysis of the food supply chain (FSC) in Iran, aiming to identify the major FLW hotspots within the supply chains and examine the magnitude and root causes of the issue. The study later shifted its focus to loss and waste throughout the wheat and bread lifecycle (WBL) due to their high importance in daily diets. The present doctoral research was conducted in Fars province, with a particular emphasis on losses at the farm level and waste in households.

The overall research was financially supported by the Food Security Center within the German Academic Exchange Service (DAAD) program, Excellence Centers for Exchange and Development (EXCEED), with funds from the German Federal Ministry for Economic Cooperation and Development (BMZ). The field study was funded by the Foundation fiat panis, Ulm, Germany.

The following sections of this chapter present the background of FLW and an in-depth literature review highlighting the data gaps and missing knowledge in the field. Additionally, the study's aim and objectives are outlined, followed by general information about the study's focus and the chosen target location. Finally, a comprehensive overview of the dissertation's content is given.

2. The Background of Food Loss and Waste

If global FLW were depicted as a country, it would be the third-largest greenhouse gas (GHG) emitter after China and the United States [1]. The stark reality is that although 800 million people worldwide suffer from undernourishment [2], the annual amount of wasted or lost food—around 1.3 billion tonnes—is two and a half times the quantity needed to feed them [3]. This issue raises fundamental questions about how we can sustainably provide food for the growing population while preventing further harm to the environment and safeguarding natural resources. Given the pressing challenge of climate change and the crucial importance of preserving biodiversity, it seems unwise to pursue a strategy of enhancing agricultural productivity by further exploiting environmental resources and converting more land into agricultural fields [4,5]. Therefore, the most rational solution is still to utilize the available food resources efficiently and effectively. Although the efficiency of food production has been enhanced, it is essential to recognize that resources are finite, and the competition for access to these resources has become increasingly intense.

The United Nations (UN) [6] has forecasted that the global population will likely exceed 8.5 billion in 2030 and reach 9.8 billion by 2050. On the other hand, predictions indicate that the global demand for food will increase by 35–56% between 2010 and 2050 [7]. Nevertheless, it is evident that the present food production system is inadequate to sustainably meet the escalating demand [8–11]. Meanwhile, FLW presents an unnecessary burden on the system, extending beyond the food production realm alone, and poses significant challenges to achieving sustainability. Understanding the relationship of FLW with sustainability requires examining its impacts on the three pillars of sustainability: social sphere, environment, and economy, as well as intergenerational justice, according to Brundtland's report [12]. In the following, the links between FLW and each sustainability pillar are explained.

2.1. Food Loss and Waste and Sustainability

2.1.1. Social Impacts

FLW has a significant impact on society, particularly by limiting access to potentially edible food and compromising food security. In other words, the more uneaten food, the more opportunities are lost for feeding people. Reducing FLW can improve all four dimensions of food security, i.e., availability, access, utilization, and stability [13]. According to the Food and Agriculture Organization (FAO), the global FLW amount is enough to feed two billion people [3]. In order to sustain the food requirements of the projected population in 2050, the world must generate an additional 6,000 trillion kilocalories per year [14]. If the current level of FLW were cut in half, an estimated 1,314 trillion kcal more food would be available each year—22% of what is needed [14].

Besides its impact on food security, wasting food is considered ethically unacceptable, and many consumers feel a moral responsibility to address it [15–21]. The general sentiment among consumers is that excessive FLW can be attributed to the unfair distribution of food, which manifests in the oversupply of certain regions and limited accessibility in others [16]. Despite consumer awareness and ethical concerns regarding FLW, substantial amounts of food continue to be lost and wasted, with the underlying causes rooted in the prevailing structures of FSCs and consumption behaviors. The relationship between FLW and social factors cannot be characterized as a linear, one-dimensional correlation but rather represents a complex, multifaceted interplay that is largely influenced by the intricate structure of FSCs.

For example, gender exhibits a bidirectional relationship with FLW. A study in Romania showed that women are more concerned about FLW than men [22]. The same study also revealed that certain aspects of women's food consumption behavior might contribute to more food waste compared to men, although the amount of waste produced by each group was not significantly different [22]. Conversely, minimizing FLW could potentially promote gender equity by increasing food accessibility and availability for vulnerable populations such as women and children [23–25].

FLW has been found to have adverse effects on public health too. Increased FLW leads to the expansion of landfills, imposing higher health risks, including cancer, low birth weight, and congenital disorders, particularly for nearby residents [26]. FLW is also indirectly linked to public health. FLW at the consumption stages has been attributed to oversupply and overconsumption of cheap food, which results in a higher prevalence of obesity and non-communicable diseases, thereby indirectly impacting public health [27,28]. Therefore, tackling the over-purchasing issue reduces FLW while positively impacting public health. Moreover, the monetary loss caused by FLW represents missed opportunities for improving societal well-being, which brings us to the relationship between FLW and the economy.

2.1.2. Economic Impacts

The monetary loss associated with FLW, excluding taking fish and seafood and calculated based on the FLW amount in 2007 and producer prices in 2009, is estimated to be USD 750 billion globally [29]. This amount is approximately equal to Switzerland's gross domestic product income, globally ranked 18th in 2020 [30]. The estimated bulk-trade value of FLW at a global level was USD 936 billion, as per FAO's report in 2014 [31]. This report estimated that the indirect costs of FLW through social and environmental impacts amount to USD 1,224.2 billion each year [31].

According to the report by the High Level Panel of Experts on Food Security and Nutrition of the Committee (HLPE) on world food security [32], FLW causes economic loss throughout the FSC in three ways:

1. Income loss for actors at the production and post-harvest stages by decreasing their work outcome;
2. Imposing economic pressure on consumers by limiting the food supply, which leads to an increase in prices;
3. Raising production costs in the long term by eroding natural resources.

The figures for FLW are typically reported as the amount of food lost or wasted. However, the economic loss varies across food groups, depending on producer cost per kilogram. For example, although meat loss and waste account for only 4% of the total FLW amount, it is responsible for 20% of the total FLW economic loss [29]. Moreover, the economic loss due to losing or wasting a single food commodity varies in different regions as production costs vary too. For instance, losing or wasting the food produced in Europe leads to higher economic loss than in Latin America [29]. The economic loss resulting from FLW also extends downstream, depending on the point of occurrence within the FSC, as additional costs such as transportation, processing, packaging, and storage accumulate [29,33]. Along with production costs, expenses for waste management also constitute a significant portion of the total economic losses associated with FLW [34,35]. Moreover, it is important to note that higher complexities within an FSC correspond to higher economic costs associated with FLW [36].

FLW negatively affects the economies of countries by limiting saving resources, hindering the efficiency of the production system, decreasing the profitability of food retail and foodservices, raising household expenses, and increasing waste management efforts [37–39]. Apart from the direct economic impacts on the production and consumption systems, the money lost due to FLW could have been spent to improve people's livelihoods, create jobs, and contribute to the gross domestic product [33,40]. Overall, although the FLW interventions require resources, and not every economic actor reaps a gain, its benefits outweigh its costs [41].

2.1.3. Environmental Impacts

FLW impacts the environment in six different ways, namely:

- GHG emission,
- biodiversity loss,
- land use,
- water use
- soil erosion,
- and deforestation [31].

The environment is burdened with all stages of the FLW life cycle, i.e., agricultural production, transportation, storage, processing, retail, preparation, recycling, and waste management [42]. FLW is responsible for 3.49 billion tonnes CO_2 equivalent [31], which accounts for about 6% of global GHG emissions [43]. To put it in perspective, the entire European Union emits about 9.8% of the global GHG [43]. Based on a review of five lifecycle assessment (LCA) studies, the carbon footprint caused by different food waste management techniques varies between 1.17 to 7.88 kg CO_2 equivalent per person each year [44]. About 95% of the food waste ends up in landfills [45], accounting for 50–60% of municipal waste [46]. Landfills alone emit 10% of the global methane (CH_4) [47]. Additionally, the contaminations of soil and water, particularly in landfills, endanger biodiversity and human health [48]. About 900 thousand hectares of land occupation and 306 km^3 of water use are associated with FLW [31]. Moreover, over 7.3 billion tonnes of soil and 1.8 million hectares of forests are lost due to FLW [31].

2.1.4. Food Loss and Waste and the Sustainable Development Goals

The multifaceted impacts of FLW on sustainability pillars are well-demonstrated in Figure 1. FLW impacts the environment and is detrimental to climate change [49]; climate change affects social well-being by endangering agricultural productivity and food security [4] and impairs the global economy [50]. FLW also jeopardizes food security [13], requiring boosting food production, which again imposes an extra burden on the environment [51]. And finally, tackling all of these issues requires more economic resources, which are limited partly due to losing and wasting food in the first place [29,52].

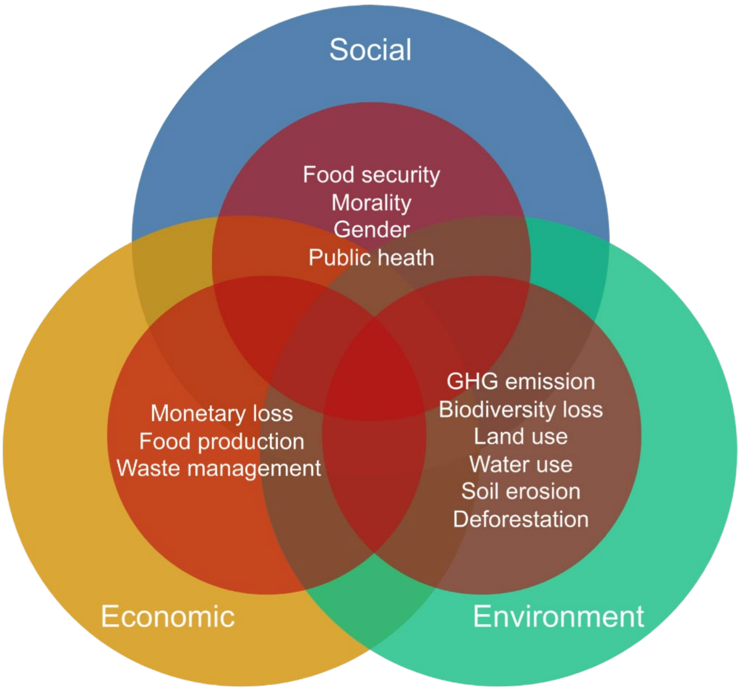

Figure 1. A schematic illustration of the impacts of FLW (indicated in red) on three pillars of sustainability; GHG stands for greenhouse gas.

Just as the generation of FLW inflicts deleterious impacts upon all dimensions of sustainability, its mitigation can serve as a countermeasure to preclude such deleterious outcomes. Therefore, urgent and pivotal actions must be taken on a global scale. In 2015, the member states of the UN agreed to reach 17 Sustainable Development Goals (SDGs) by 2030 [53]. The reduction of FLW is an integral part of SDG 12, as reflected in its third objective, SDG 12.3, which aims to “halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses” [53]. However, according to FAO [13], reducing FLW can contribute to or would be affected by at least 13 other SDGs, namely:

- SDG 1 (no poverty),
- SDG 2 (zero hunger),
- SDG 5 (gender equality),
- SDG 6 (sustainable water management),
- SDG 7 (affordable and clean energy),
- SDG 8 (decent work and economic growth),
- SDG 9 (industry, innovation, and infrastructure),
- SDG 10 (reduce inequalities),

- SDG 11 (sustainable cities and communities),
- SDG 13 (climate action),
- SDG 14 (life below water),
- SDG 15 (life and land),
- and SDG 17 (partnership for the goals).

Finding effective solutions to reduce FLW firstly requires establishing what FLW is and where and why it occurs. The following subsection describes the definitions of FLW, as well as its occurrence and general reasons throughout the food production and consumption cycle.

2.2. Food Loss and Waste Definitions and Scope

It was at the 1974 World Food Conference in Rome that the US Secretary of State first raised the matter of food loss [54]. In his speech, Henry Kissinger only mentioned the post-harvest loss and reported that 15% of agricultural products were lost after harvesting in the US [54]. Evidently, the oldest citable definition of FLW was described by Bourne [54], which reads: “any change in the availability, edibility, wholesomeness or quality of the food that prevents it from being consumed by people” (p. 6). This definition was later used by [55]. A considerable inconsistency exists in the FLW definitions across studies and reports [13,56,57]. Therefore, researchers have tried to evolve the FLW definitions to harmonize a common understanding of the phenomenon. As a result, various definitional frameworks have been formulated in the most important sources.

The general definition for FLW is the amount of food intended for human consumption that remains uneaten, regardless of the stage of the supply chain or the reasons for its wastage [32,56,58]. FAO [59] offers another definition of FLW that is based on the underlying reason for food loss rather than the stage in the supply chain. This definition encompasses any decrease in the amount of food at any point along the supply chain, including during consumption, and considers food waste to be a component of food loss. According to this definition, food waste is deliberately removing consumable food from the FSC or disposing of damaged or spoiled food.

A more specific definition is based on the FSC stage of FLW occurrence. The FSC is defined by FAO [60] as a “connected series of activities to produce, process, distribute and consume” (p. 10). One of the oldest definitions in this context was provided by Parfitt et al. [61], which refers to the FLW at production stages as food loss and at consumption stages as food waste. However, the boundary between production and consumption segments could be context-specific and varies across studies [62]. The FAO [13] attempted to clarify this boundary and the definitions to cater for compatibility with SDG 12.3 by referring to food loss as the decrease in mass of edible food along the upstream (production) stages, i.e., primary production, transportation and storage, processing, and distribution and wholesale, and defining food waste as the food discarded from the food cycle at the downstream (consumption stage), i.e., retail, foodservice, and households. Figure 2 illustrates these two definitions by specifying the FSC stages.

Some reports or studies also consider qualitative loss, which refers to declining food quality attributes, as a component of FLW [13,29,59,63,64]. Corrado and Ardente [65] argue that the subjectivity of some food quality characteristics hampers data comparison across studies. Nonetheless, the qualitative loss ultimately leads to quantitative loss as food materials that do not have desirable qualitative attributes or are unfit for human consumption will be removed from the FSC [63]. Nonetheless, most FLW studies report the absolute or relative mass reduction of food to minimize subjectivity and facilitate data comparison and loss reduction monitoring.

Another differentiation in FLW definitions is between avoidable and unavoidable FLW. In principle, parts of food that are considered inedible are classified as unavoidable FLW [65]. According to FAO [13], inedible portions of food do not count as FLW. By contrast, the portions of food products that are potentially edible but are lost or wasted regardless of the reason are referred to as avoidable FLW [35]. Nevertheless, because the edibility of food parts varies across different geographical and cultural settings, there is no distinct definitional boundary between avoidable and unavoidable FLW [60,65]. Even in regions such as the European Union, where a precise classification of edible and inedible foodstuffs exists [66], different countries, or even ethnic groups, may have varying perceptions of what is considered edible [67,68]. For example, while eggshells might be considered inedible, they can be utilized for human consumption besides their industrial uses [69]. Therefore, the term “possibly avoidable FLW” would be used to express the uncertainty in the distinction between avoidable and unavoidable FLW.

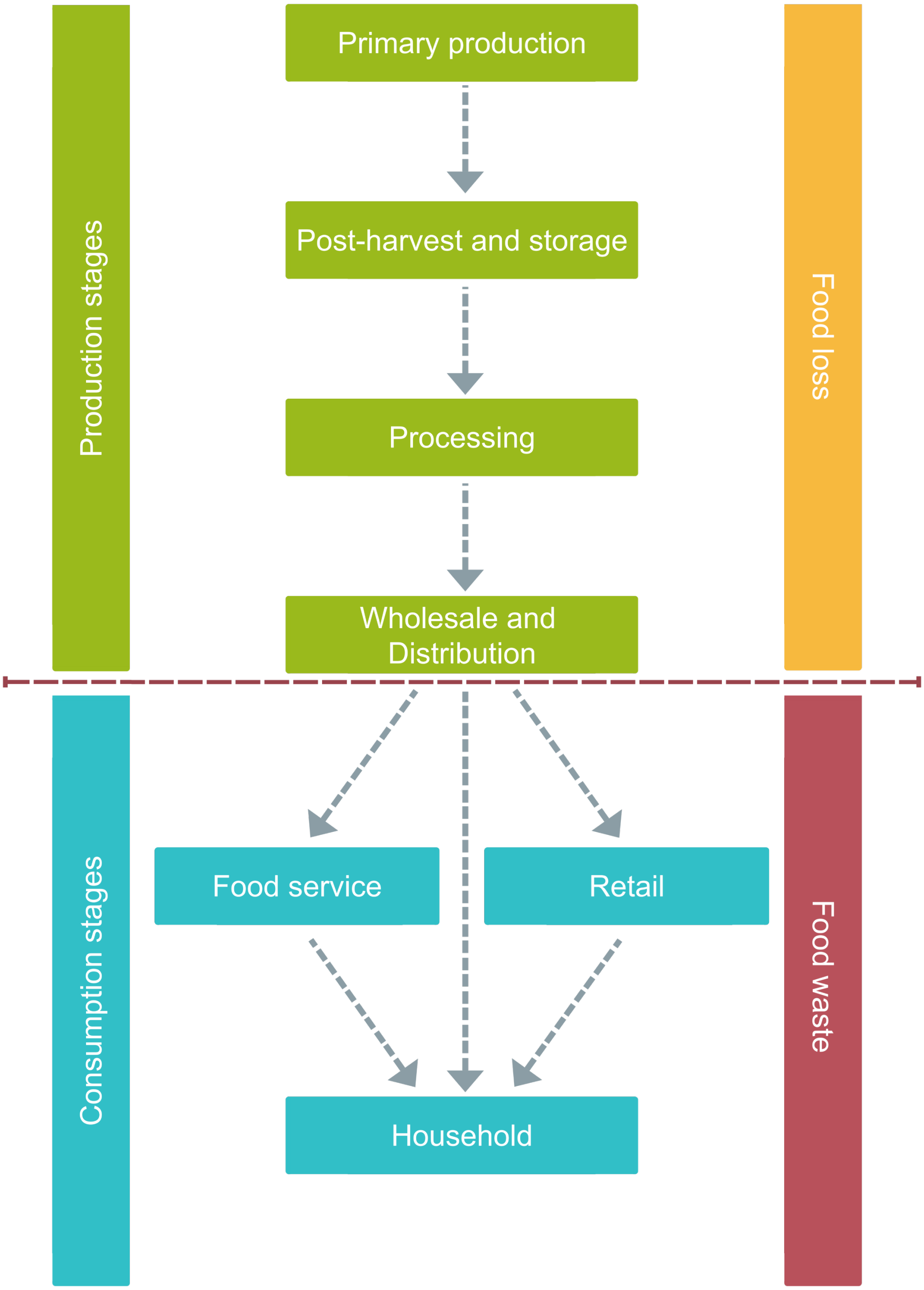

Figure 2. The scope of food loss and food waste along the food supply chain based on the 2019 definition by the Food and Agriculture Organization [13].

Lastly, the inclusion of food materials utilized for purposes other than direct human consumption as part of FLW varies depending on the specific definitional framework. The strict definition implies that any food item diverted from its final destination, i.e., human consumption, is lost or wasted [54,70]. Selecting inclusion and exclusion criteria to define FLW is context-specific and varies across studies depending on where the researcher chooses to draw the line on the spectrum of food utilization, which ranges from direct human consumption to its indirect consumption (e.g., feeding domestic livestock that will eventually be consumed by humans) and other beneficial uses (e.g., compost or bio-based material production) [65]. As an illustration, the orange pomace resulting from juice extraction could be considered avoidable food loss, as it could have been directly consumed by humans had the oranges been eaten fresh. However, the same by-product can be utilized in the production of ice cream [71] or baked goods [72], and as such, it would not be classified as food loss. FAO's 2019 report [13] excludes food utilized for economic purposes other than direct human consumption from FLW, despite the potential economic losses that may arise.

Regardless of the inconsistencies in the FLW definitions, multiple studies and reports have gathered data at the national and international levels intending to build an image of how much food is lost or wasted. Although the data inconsistency makes comparison across studies difficult, the efforts to report the FLW levels in different regions of the world remain valuable and will enhance reaching a more realistic and precise perception of the FLW situation over time. The following subsection summarizes general information about the FLW global statistics and trends. The terms food loss and food waste are used hereafter according to FAO's 2019 definition of FLW, as illustrated in Figure 2.

2.3. The State of Global Food Loss and Waste

The FAO's initial global report on FLW in 2011 [3] revealed that roughly one-third of food is lost or wasted. FAO reported that the total FLW amount was around 1.6 billion tonnes in 2007, 1.3 billion tonnes of which were edible parts, suggesting that more than 80% of the FLW generated could have been averted. The FLW amounts vary across food groups. Figure 3 shows how much of the six main food groups are globally lost or wasted based on FAO's 2015 report [73]. The FLW varies between 20% and 50%, with root crops, fruits, and vegetables being lost and wasted the most, and oilseeds, meat, and dairy products being lost and wasted the least. While these numbers provide a general estimation of the state of FLW, the actual amounts vary vastly across regions with different cultures, development levels, and geoclimatic contexts [3,13,47]. Furthermore, there are notable variations in the levels of loss and waste among different food commodities, to the extent that horticultural products can experience losses or waste of up to 100% under certain circumstances [61]. The information presented provides a broad understanding of FLW; however, significant data gaps and knowledge deficits remain.

Figure 3. The amount of FLW in percentage among food groups; Source: FAO [73]; Photo copyright: University of Hohenheim.

3. Literature Review

The literature review presented in this subchapter emphasizes the significant data gaps and knowledge deficits in researching FLW, underscoring the need for sustained efforts to address the issue and promote sustainable food systems.

In recent years, there has been a considerable increase in efforts to understand and quantify FLW, particularly during the past two decades. Consequently, the current state of FLW is becoming increasingly comprehensible and lucid. A systematic review by [74] shows that out of 202 articles focused on FLW in 84 countries between 1933 and 2014, around 60% were published after 2006. A similar study by Affognon et al. [75] revealed that from 213 articles focused on post-harvest food loss in Sub-Saharan countries between 1980 and 2012, over half of them were published after 2005. These studies highlight the growing importance of the issue and the level of attention it has received. However, despite extensive efforts to investigate FLW, data incomparability and uncertainty have remained a significant limitation in the literature [13,47,62,74], which could be one of the underlying reasons for the poor progress toward reducing FLW [75].

3.1. Data Incomparability

The discrepancies in data between older and more recent studies, as well as inconsistencies across various sources, represent a significant obstacle to monitoring FLW reduction. A case in point is the apparent shift in earlier global estimations compared to more recent ones. Figure 4 illustrates the distribution of FLW across the various stages of the global FSC, as reported by FAO in 2013 [29]. It is worth noting that the FAO's 2013 report [29] used the FLW data reported in 2011 [3] and presented them based on the segments of the FSC where loss or waste occurs, focusing mainly on assessing the environmental impacts of FLW. According to recent reports, FAO [13] estimated that food loss amounts to 14%, while the United Nations Environment Programme (UNEP) reported that global food waste is about 17% of the total food produced [47]. Accordingly, as Figure 5 illustrates, approximately more than half of the global FLW occurs at consumption stages.

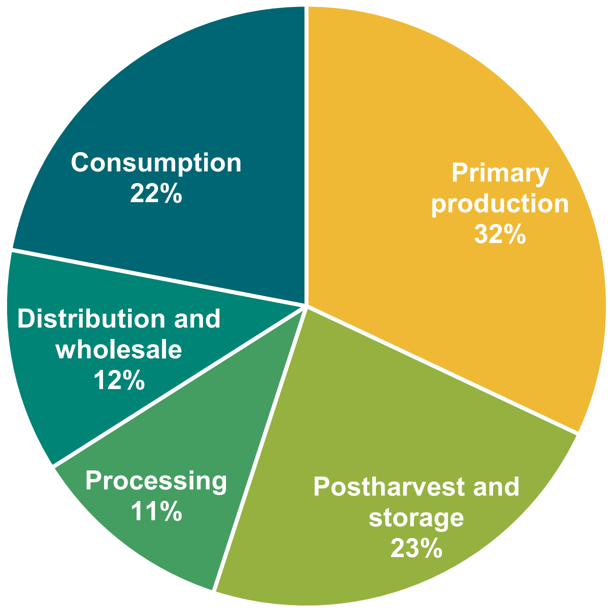

Figure 4. Share of each FSC stage in the global FLW based on the 2013 report by the Food and Agriculture Organization [29].

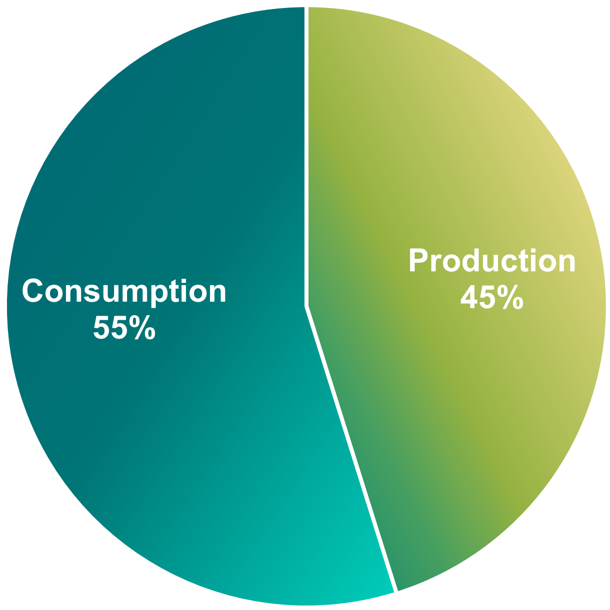

Figure 5. Share of the production stage (after harvest/catch/slaughter up to, but excluding retail) and the consumption stage (retail, foodservice, and households) in the global FLW based on the 2019 report by the Food and Agriculture Organization [13] and 2021 report by the United Nations Environment Programme [47].

Figures 4 and 5 reveal an evident disparity between FLW estimates from 2011 and those from 2019 and 2021. Nonetheless, this disparity is not solely due to changes in the FLW levels. Although new technologies and practices, such as precision agriculture, improved packaging, and better storage facilities, have also contributed to the reduction of food loss at the production stage [76] and hence change in the FLW levels, the data inconsistencies can be attributed to multiple other factors, including changes in definitional frameworks, implementation of different quantification methods, availability of more detailed and standardized data, improvements in data collection methods, and a better understanding of the complexity of the FSC [61,77]. Inconsistencies in the FLW definitions can particularly hinder the comparability of data across studies.

Substantial conceptual and methodological improvements have been made to facilitate future data collection and comparisons, but definitional discrepancies still exist [62]. Despite the efforts by international organizations such as FAO [3,13,29] and UNEP [47] to define a clear scope, considerable inconsistencies still exist in identifying the FSC segments and distinguishing between food loss and food waste, even in systematic reviews. As seen in the earlier example discussing the contribution of various FSC segments to global FLW, discrepancies between older and more recent reports can be due to modifications in the definition of scope. In the more updated reports, there is a clear distinction between the production and consumption stages, with production starting from primary production up to but excluding retail, while consumption includes retail, foodservice, and household [13,47]. The 2013 report [29] failed to provide a clear distinction between the segments to be included in the distribution stage, such as foodservice and retail, resulting in confusion and uncertainty. Moreover, the more recent reports rely on more primary FLW data at various stages, providing a more detailed picture of the sources of FLW compared to the 2013 report.

Definitional inconsistencies in sub-global level studies are even more pronounced. The inclusion of FSC segments for assessing FLW varies across studies [62]. Figure 6 illustrates how meta-analyses or systematic reviews have used various conceptual frameworks to define FLW and analyze related data. The figure shows which FSC segments are included in each study and how the terminologies have been formulated. The disparity is apparent across these studies, which impedes comparisons. Identifying the structure of FSCs for various food commodities in different regions is the key to establishing harmonized and standardized conceptual frameworks for monitoring and reducing FLW in line with SDG 12.3.

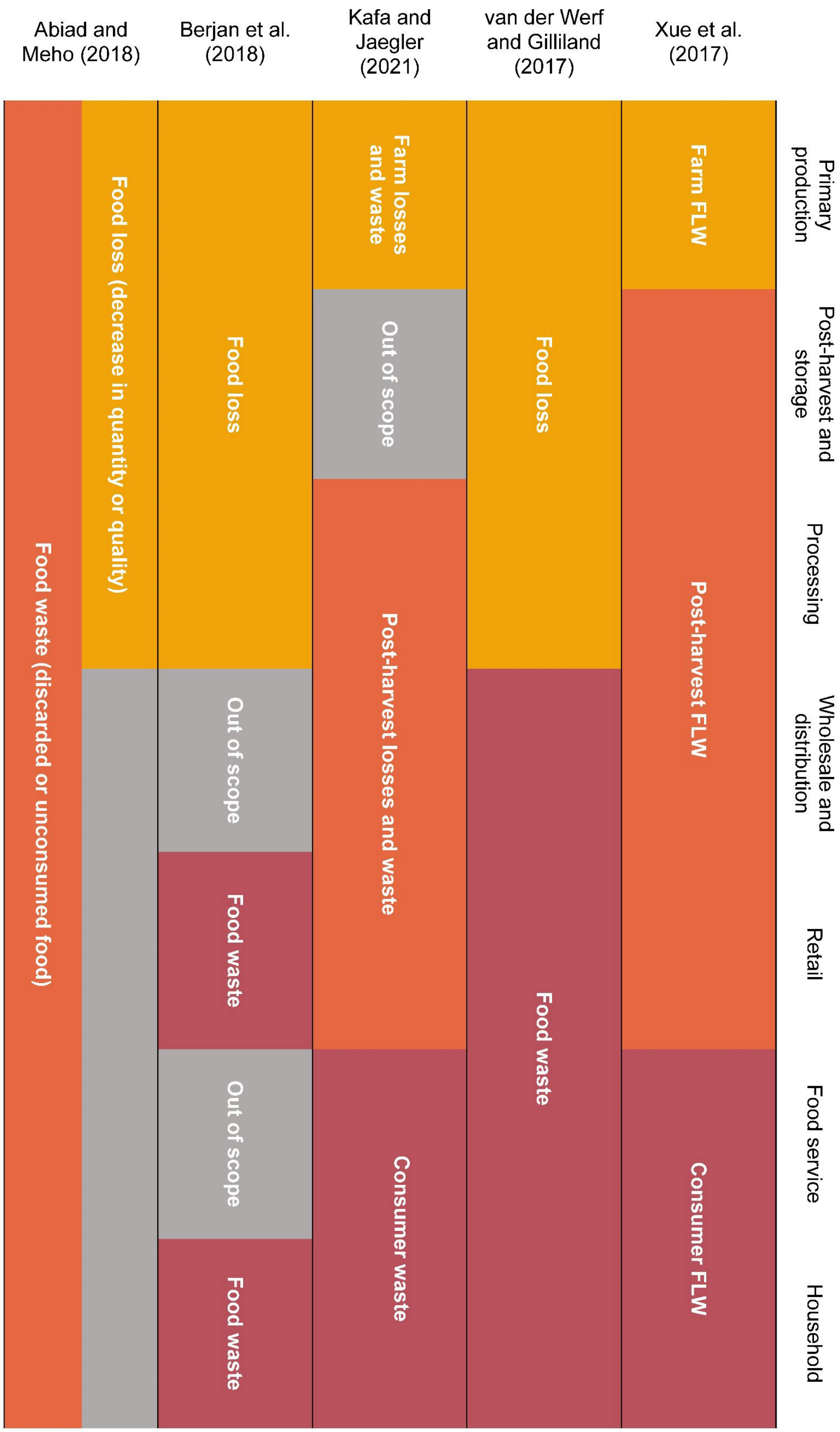

Figure 6. Examples of different conceptual frameworks used in systematic reviews and meta-analyses studying food loss and waste.

In light of the evidence provided, implementing the latest definitional frameworks provided by FAO [13] and UNEP [47] is crucial in ensuring data comparability and effective monitoring of FLW reduction efforts. The new frameworks provide a clear distinction between the segments within the production and consumption stages, allowing for more accurate identification of sources of FLW. These frameworks also incorporate primary FLW data at various stages, including data collection from producers, processors, distributors, retailers, foodservice establishments, and households, thereby providing a more comprehensive and detailed picture of FLW. Nonetheless, data uncertainty is still an outstanding issue that requires attention.

3.2. Data Uncertainty

Researchers are increasingly acknowledging the lack of standardized and accurate FLW quantification methods as an underlying reason for the uncertainty of the existing data [14,75,78–80]. Nonetheless, identifying and understanding the existing methods and their application in various contexts are prerequisites to addressing this issue. Existing methods analyze FLW at three scales:

- Macroscale or global;
- Mesoscale or regional;
- Microscale.

Macroscale involves using balance sheets to analyze the food material inputs and outputs along FSCs at large scales [3,29]. Another approach utilized in FAO's 2019 and UNEP's 2021 reports [13,47] involves gathering and extrapolating existing data at subordinate scales to estimate the magnitude of global FLW. Mesoscale FLW estimations are conducted using material flow analysis [81] by comparing the community's calorie requirements and the available energy through food supply [82], or by conducting systematic reviews [75]. Microscale usually involves studying a specific FSC by conducting interviews or calculations based on available statistics in the agri-food system [81,83] or a particular FSC segment by surveying individuals [84] [85] or physically measuring FLW [86].

The robustness of data at each scale depends on the reliability of the information obtained at its subordinate scale. Therefore, data acquisition at the microscale becomes especially important to portray a realistic state of FLW at regional and global levels. More precise and thorough results can be achieved by examining FLW at a particular stage of FSC [8]. Moreover, since various food commodities possess distinct characteristics, the causes of loss and waste for each may differ [61,87]. Therefore, studying single food items or groups can help identify the root causes of loss or waste occurrence and develop effective policies that specifically address them [83]. There is still a need to enhance the precision and standardization level of FLW measurement methods.

Efforts to develop standardized methods to measure FLW have improved the accuracy and reliability of data at the microscale [13]. Examples of such attempts are the REFRESH methods proposed within the European project, Food Use for Social Innovation by Optimizing Waste Prevention Strategies (FUSIONS) [88,89] and the method introduced by the Waste and Resources Action Programme (WRAP) in the United Kingdom [90]. The primary focus of these two methods is measuring food waste at the household level. However, these methods are mainly developed to measure household food waste in European countries and may lack specificity in other contexts. Therefore, the implication of such standard methods remains limited to developed countries [74], which raises the issue of data gaps, particularly in developing countries.

3.3. Data Gaps

Although estimates of FLW have been calculated for all countries worldwide, a considerable proportion of these estimates rely on proxy data and modeling rather than primary data [13,47]. The implementation of viable FLW reduction policies rests upon the availability of relevant, up-to-date, accurate data [62]. Despite considerable progress in FLW measurement since FAO's first report in 2011 [3], relevant and accurate data on the loss and waste of different food commodities and geographical settings are scarce [62]. The existing primary data on FLW are mostly from developed countries [13,47]. According to a systematic review by Xue et al. [74], the main FLW data gap exists in developing countries. Moreover, the majority of studies used secondary data resulting in low reliability of the findings [74].

Prominent examples of such studies include the works of Zorpas and Lasaridi [91], which examined food losses and waste in various developing regions in Asia and Africa; Bond et al. [92], who studied household waste across different continents, including Sub-Saharan Africa and South and Southeast Asia; Choudhury [93], who examined postharvest practices in Pakistan and Nepal; Kader [94], who investigated postharvest losses in Egypt and Venezuela; and Winkworth-Smith et al. [95], who explored food waste across multiple stages, primarily in developing countries such as Sub-Saharan Africa and South and Southeast Asia. These studies illustrate the widespread use of secondary data in FLW research. Notably, the FLW data in developing countries bear more uncertainty than the ones in developed countries [47]. In a meta-analysis of over 800 documents about FLW in Sub-Saharan African countries, Affognon et al. [75] found that only 25% of the studies resulted in data that could be considered satisfactory. Therefore, it is crucial to collect data anew and examine the accuracy and validity of the existing data in developing countries [8].

Moreover, determining the factors associated with FLW occurrence along the FSC is necessary to understand better how, why, and how much food is lost or wasted at each stage and to find effective solutions to reduce it [61]. Food loss usually occurs due to technological and infrastructural incapacity, knowledge and skill incompetency, production inefficiency, weather conditions, or legislation requirements [13,29,83,96–98]. The food is wasted at the consumption stage mainly caused by market structure, aesthetic preferences, and consumers' food shopping, individual behavior, and consumption habits [29,61,99]. However, the underlying reasons for FLW are specific to the context of FSC structure and sociogeographical settings [100]. Once again, the key knowledge gap regarding the causes of FLW is particularly pronounced in developing countries [101].

Apart from the existing data gaps and missing knowledge in developing countries, other compelling reasons exist to underscore the significance of studying FLW in these nations. For example, food insecurity is more prevalent in developing countries, with undernourishment affecting an estimated 20% of the population, compared to 9.2% in developed countries [3]. Additionally, crop production in developing countries accounts for 77% of threats to biodiversity, whereas the figure is 44% in developed countries [29]. These highlight the pressing need for further investigation into FLW in developing countries. However, not all developing countries are equally important in terms of collecting FLW data and prioritizing countries with the highest potential for FLW reduction could maximize the impact of data collection efforts [62]. Countries, where FLW occurrence is more complex, should be prioritized in data collection efforts to better understand the underlying causes of FLW and design effective reduction policies [102].

In general, the share of food loss in total FLW of developing countries is higher than in developed countries where food waste is more prevalent [3,13,103]. The average per capita food waste in developing countries is around 14 kg/year, while it is approximately 85 kg/year in developed countries [3]. Food waste in Sub-Saharan Africa is less than 5% of the region's FLW, whereas this share is around 35 to 40% of the FLW in Europe, North America, and Oceania [29]. On the other hand, post-harvest and storage food loss in Sub-Saharan Africa is around 35%, compared to less than 10% in North America and Oceania [29]. However, while it is generally true that developed countries have a higher proportion of food waste, it is important to acknowledge that certain developing countries also experience high levels of food waste, as well as considerable food loss during production. A notable case in point is the Middle East and North Africa (MENA) region.

In the MENA region, where more than half of the food is imported, and the FLW rate is above the global average at 250 kg per person annually, food loss occurs primarily at production and post-harvest stages, attributable to limited technological infrastructure [104]. Nevertheless, a substantial proportion of the FLW in the MENA region (32%) takes place at the consumption stage [105]. The countries in North Africa, West, and Central Asia generate only 6.4% of the global FLW, but their per capita FLW is one of the highest in the world – 216 kg per year [3,29,32]. In affluent MENA countries, such as the Kingdom of Saudi Arabia, high levels of food waste are observed at the consumption stages, primarily due to lavish lifestyles and inexpensive food [106].

The 2021 Food Sustainability Index report [107] indicates that food waste levels are estimated at 151 kg per person per annum in Saudi Arabia and 134 kg per person per annum in the United Arab Emirates. The MENA countries heavily rely on irrigation for food production, which, combined with water scarcity, exacerbates the issue of FLW in this region. According to Kummu et al. [108], FLW accounts for 33% of water use in North Africa, West, and Central Asia, ranking the region third globally after North America and Oceania (35%) and Latin America (34%). Considering the evidence presented, there is a justifiable need to prioritize research on FLW in the MENA region.

4. Problem Statement

Following reviewing the literature, this subchapter provides an overview of the main challenges and limitations associated with research on FLW. It is evident that definitional discrepancies are a major contributing factor to data inconsistencies and incompatibilities in FLW research. In order to address this issue, a viable solution is to adopt the standard definitions outlined by the FAO [13] and the UNEP [47]. Additionally, it is crucial to differentiate between avoidable and unavoidable FLW to accurately represent the FLW landscape and identify the portion of FLW that can be reduced.

Furthermore, the issue of data uncertainty arising from a lack of up-to-date information and a relatively high reliance on estimates based on proxy data calls for a pivotal approach. Therefore, a bottom-up approach is necessary to tackle the challenge of data uncertainty in FLW research. This approach involves collecting primary data at the microscale level of individual segments of the FSC and single food items. Collecting data at this level helps provide accurate information about FLW, which serves as a puzzle piece. When such pieces are combined with others, a more realistic portrayal of overall FLW can be achieved.

Nevertheless, it is crucial to obtain a comprehensive understanding of the supply chain framework and material flow related to the food item in question. This approach allows for pinpointing loss and waste hotspots and a more detailed understanding of the causes and impacts of FLW at each stage of the FSC, thereby enabling targeted interventions and policy measures. Additionally, there is an urgent requirement for enhancing quantification methods and adapting them to the specific study context to enhance the precision of FLW data.

Finally, the lack of data on FLW in developing countries highlights the necessity of studies that concentrate on data collection in these regions. The countries in the MENA region appear to be of particular importance, given their challenges in food production due to water scarcity and the high amounts of FLW generated at both production and consumption stages. Among these countries, those where data gaps exist the most require extra attention and need to be prioritized.

5. Aim and Objectives

Based on the observations and arguments presented above, the present study aimed to investigate the loss and waste of a significant food item in one of the countries in the MENA region. Iran, as a major country in the MENA region, was chosen to be the focus of the study due to its significant geopolitical, economic, cultural, and historical importance in the region and its impact on regional and global affairs. Additionally, the study was oriented to investigate loss and waste throughout the WBL due to their importance as staple food consumed by a large population globally. Given the importance of Fars province as one of the major wheat production regions of the country, the study concentrated its focus on wheat production in this area and bread consumption in its capital, Shiraz. The reasoning behind these decisions is thoroughly clarified in the following chapters, with Chapter 4 providing the most comprehensive explanation.

Accordingly, this investigation aims to address the following objectives:

1- To identify and map the wheat lifecycle in Fars province, with a particular focus on bread as the end product in Shiraz.
2- To identify loss and waste hotspots throughout the WBL and determine the points where data collection is most necessary.
3- To examine ways to improve the accuracy of FLW quantification methods.
4- To quantify the wheat loss or bread waste at the most significant segment of the lifecycle and examine the reliability of the existing data.
5- To investigate the underlying reasons and associated factors for wheat and bread loss and waste at these hotspots.
6- To examine possible solutions that could potentially help reduce wheat and bread loss and waste.

6. Background Information about the Study Region and Target Food

This section offers an overview of Iran, as well as the status of wheat production in the country and the significance of bread in the local diet.

Iran is located in West Asia and, with an area of 1,648,195 km^2, is the second largest country in the Middle East after Saudi Arabia. According to the most recent national census, Iran's population was around 80 million in 2016 [109]. However, based on the World Bank's estimation for 2021, the country's current population is around 85 million, placing Iran as the second most populated country in the MENA region after Egypt [110].

With the world's second-largest gas reserves and fourth-largest oil reserves, Iran holds significant natural resource wealth [111]. However, the country has struggled with unrelenting economic challenges during the last decades, mainly due to international sanctions [112]. Despite the slight economic growth in the last two years, mainly driven by oil income, Iran still experiences a severe recession [112]. The country's current gross domestic product (GDP) has remained unchanged since 2010 and 2011, currently ranking 19th globally with an approximate value of 249.7 USD billion [112]. Moreover, the per capita GDP is 2936.3 USD, at the same level as in 2004 and 2005 [112]. To put it in perspective, Switzerland, with a per capita GDP of almost 92,000 USD, ranks 6th globally, highlighting its high economic prosperity [30]. On the other hand, Albania, with a per capita GDP of 6,600 USD, represents the median value, indicating a moderate economic level [30]. Iran's neighboring country, Türkiye, holds the 99th place with a per capita GDP of over 96,000 USD, showcasing its relatively high economic performance [30]. The economic situation of Iran is explained further in detail in Chapter 4.

Iran is a four-season country with a wide range of climatic conditions. The country has two major mountain ranges extending from the northwest to the northeast (Alborz) and the southwest (Zagros). Two deserts, Dasht-e Kavir and Dasht-e Lut, occupy 77,600 and 51,800 km^2 of the country's central, eastern, and southeastern regions. Figure 7 illustrates the geographical location of Iran in West Asia, as well as the climate conditions across the country and the study region, Fars. The margin of the Caspian Sea in northern Iran has humid and very humid climate conditions, while other climate zones vary from semi-humid and semi-arid in the northwest to arid and super-arid in the south and southeast. The average maximum temperature varies from 15.59–17.85°C in the northwest and northeast to more than 30.83°C in the south, particularly along the Persian Gulf and Oman Sea [113]. The average minimum temperature ranges from 1.40–3.59°C in the northwest to more than 19.35°C in the south and southeast [113].

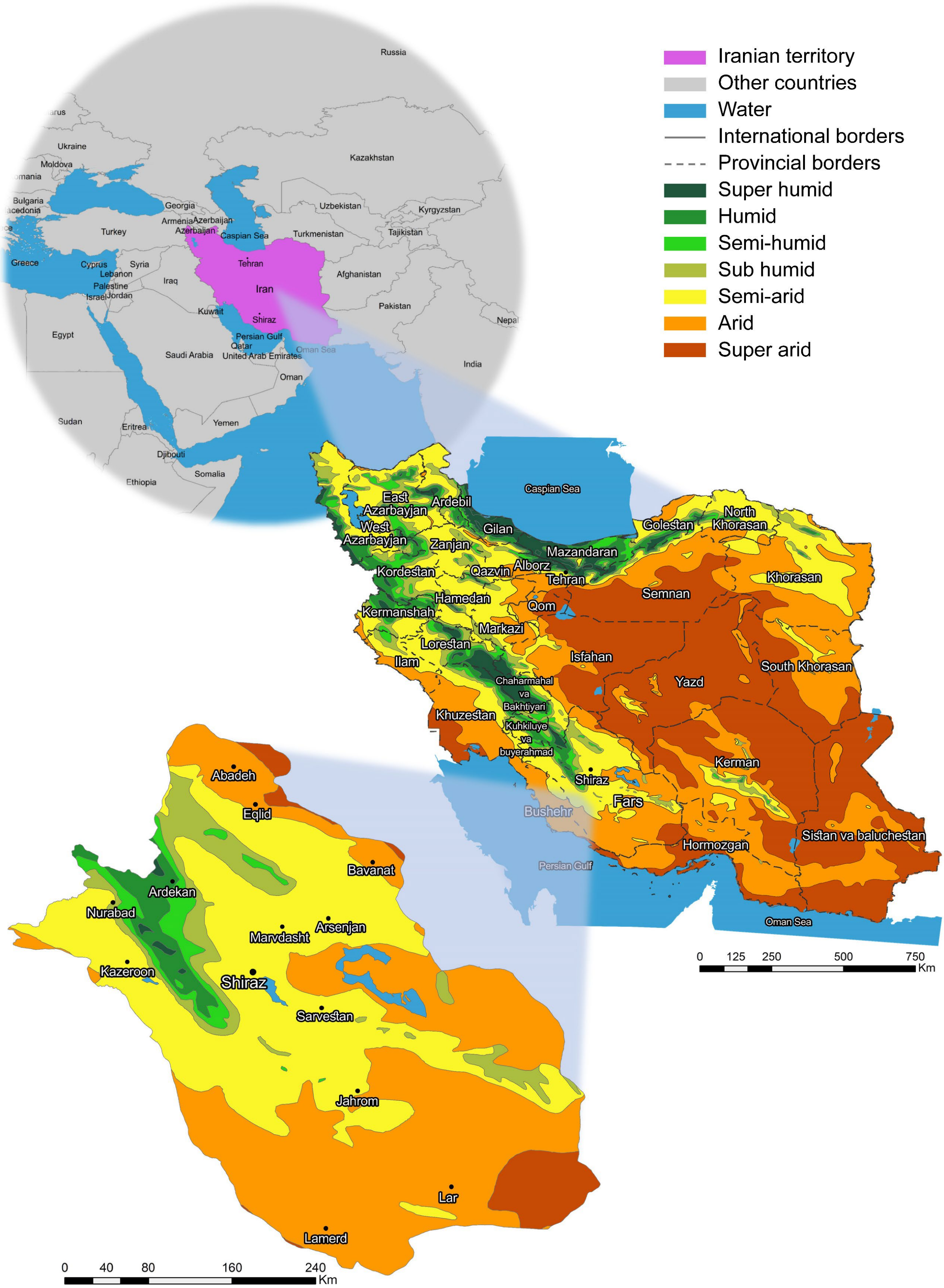

Figure 7. The geographical location of Iran and the climate condition across the country and the Fars province; Data source: Iran Meteorological Organization.

Figure 8 provides an overview of Iran's arable lands based on data from 2020 and 2021 published by the Statistical Centre of Iran [114]. About 10% (15.7 million ha) of Iran's total area consists of arable lands, around 9.5 million ha of which (over 60%) are rainfed [114]. More than 12 million ha of the total arable lands are under annual cultivation, over 86% of which comprise only five products: wheat, barley, alfalfa, rice, and peas [114]. Wheat production occupies over 55% of the arable lands used for annual plants. More than two-thirds of wheat production in Iran relies on precipitation.

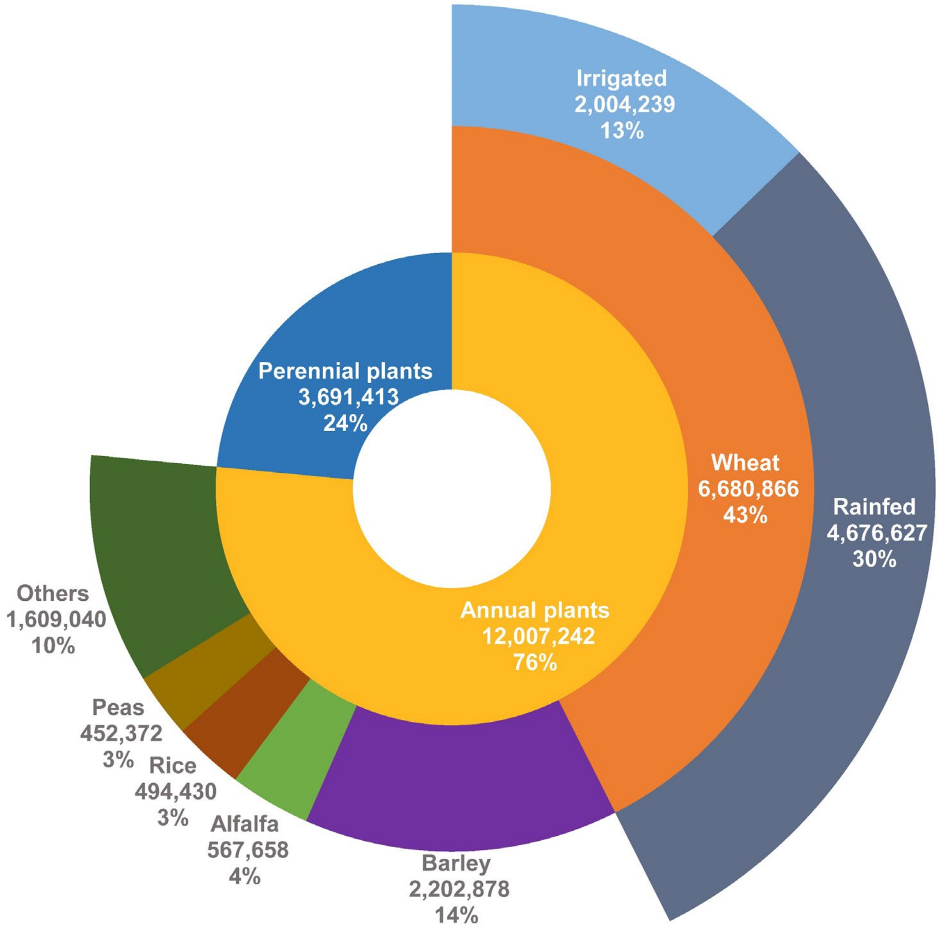

Figure 8. The area of arable lands in Iran and shares of different plant cultivations in hectares and percentages based on the data from 2020 and 2021; Source: Statistical Centre of Iran [114].

Fars province holds significant importance for the country's wheat production. With an area of 122,608 km^2 and over 4.8 million residents, Fars is Iran's fourth largest and fourth most populated province [109]. Located in southern Iran, Fars has optimal climatic conditions for wheat production. Although Fars ranked 11th in terms of the area under wheat cultivation (261,781 ha) in 2020, this province, with 724,380 tonnes, was the second-largest wheat producer after Khuzestan Province [114]. Khuzestan allocated the largest area for wheat cultivation (921,069 ha), yielding 2,120,375 tonnes of wheat [114].

Shiraz is the capital of Fars and is considered one of the oldest cities in the country. With a population of around 1.9 million, Shiraz is the fifth most populous city in Iran and a major economic and cultural center [109]. Over the past few decades, migration from rural areas to Shiraz has seen a noticeable surge. From 2012 to 2017, around 144,000 people migrated to Shiraz nationwide, with more than 87,000 coming from other areas within Fars province [115]. The urban population in Shiraz has increased due to socioeconomic segregation, as the poorer residents strive for better access to vital services like schools, health centers, and major roads [116]. Moreover, the city is known for its rich history, stunning architecture, and gardens. Shiraz is also home to several universities, museums, and historical sites, such as the Persepolis, the ceremonial capital of the Achaemenid Empire [117].

The study of household food waste in Shiraz holds great importance, especially considering the city's fast population growth and the significant proportion of young and dynamic residents highlighting the city's vibrant and evolving nature. Approximately 40% of the city's population is under the age of 50 [109]. A study by Zarei and Ahmadi [118] unveiled a notable transformation in dietary habits among the residents of Shiraz. The study found that over 50% of the younger generation, aged approximately between 15 to 26, have embraced a modern or near-modern nutritional pattern, while the traditional pattern was more prevalent in around 80% of the older generation, with ages ranging from 41 to 57 ($P \leqslant 0.05$) [118]. The findings highlight a significant generational shift in dietary preferences and choices, indicating a clear distinction between the dietary habits of the younger and older generations in Shiraz, which may lead to an increase in food waste generation, as previously discussed. Considering the importance of bread in Iran's local diet, studying household bread waste in Shiraz is crucial in understanding and addressing the potential increase in food waste resulting from the shift in dietary habits from traditional to modern patterns in the city. This shift may lead to changes in consumption behavior, preferences, and the way households handle and dispose of bread, potentially impacting food waste generation.

The significance of wheat in Iran's economy cannot be overstated, as the country's customary cuisine revolves around wheat bread as the primary staple, while rice serves as the secondary staple [119]. Iran is recognized as one of the centers of origin of wheat (*Triticum aestivum L.*) in the world [120], and bread has been a staple in the country for centuries. Bread holds great cultural and symbolic significance in the country's local diet is typically consumed with every meal and is a symbol of hospitality, community, and unity [121]. Sharing bread is considered a sign of friendship and generosity in Iranian culture, and bread has a significant presence in the country's literature [121].

Moreover, bread is often used in religious and cultural ceremonies, such as weddings, funerals, and religious observances. Bread's nutritional value is also recognized in Iranian culture, with many Iranians considering it a necessary part of a healthy diet [122]. The importance of bread in Iran's local diet can also be seen in the government's policies, with bread subsidies being a longstanding feature of Iran's economic policies. Overall, bread plays a central role in Iran's local diet, culture, and identity, making it a significant and enduring part of the country's culinary heritage.

The most widely consumed types of bread in Iran are classified into two primary groups: traditional bread and non-traditional bread, also known as bulk bread. The Iranian National Standards Organization (INSO) has compiled two main food law handbooks [122,123] for each category, which outline detailed technical specifications and required standards. Based on these handbooks, there are four types of traditional bread, including lavash, sangak, barbari, and taftoon [122], and six types of non-traditional bread, including baguette, hamburger bun, sandwich or mini-baguette, broetchen or bread roll, toast, and Non-traditional barbari or bulk barbari [123]. The detailed specifications for each bread type are provided in Chapters 2, 4, 5, and 6. This research does not cover region-specific or ethnically-specific bread variations that are not widely consumed throughout the country.

7. Content of the dissertation

This section provides a structural overview of this cumulative dissertation and aims to guide readers in understanding the scope and structure of the doctoral research presented in this work. Chapters 2 to 6 of this dissertation present five peer-reviewed articles written based on the data collected within the current doctoral project. The primary data used in the present work were collected through two surveys and one laboratory examination. Overall, Chapters 2 to 6 provide a comprehensive analysis of wheat and bread loss and waste in Fars and propose potential solutions to mitigate the issue.

<u>The articles presented in Chapters 2 and 3</u> are written based on the data and insights obtained from the first survey conducted in October 2018. This survey involved expert interviews with stakeholders and practitioners actively engaged in the WBL within the geographical context of Fars. <u>The article in Chapter 2</u> aimed to map the WBL in Fars, identify loss and waste hotspots, evaluate the data availability level at each segment of WBL, and determine which areas require further research. The primary aim of this article was to tackle research objectives 1 and 2. Drawing upon a subset of the interviews conducted in the first survey, <u>Chapter 3</u> provides a comprehensive account of the qualitative assessment that examines the extent and drivers of loss in wheat farms. Additionally, this chapter delves into the identification of viable strategies to mitigate such losses, emphasizing the potential role of cooperatives. By addressing these aspects, this chapter effectively responds to research objectives 5 and 6.

Based on the observations and preliminary findings derived from the data excerpts obtained during the first survey (as outlined in Chapter 2), the research direction was subsequently refined to emphasize the quantification of bread waste in households in Shiraz. Therefore, the second survey was conducted from December 2018 to August 2019, involving surveying 419 households in Shiraz. The primary goal of this survey was to quantify bread waste at the household level. Additionally, the survey sought to collect data on the dietary patterns and socioeconomic status of households, aiming to explore their relationship with the level of bread waste. Examining the link between household dietary patterns and socioeconomic status with bread waste is of utmost importance as it enables the identification of underlying factors contributing to high levels of waste. Moreover, this methodological approach facilitates the development of targeted interventions and educational campaigns to promote sustainable consumption practices.

Accordingly, the households were interviewed using a questionnaire that consisted of three sections: a self-assessment recall questionnaire aimed at gathering information on the amount of bread waste, as well as consumers' bread purchasing and consumption behaviors; a food frequency questionnaire designed to collect data on the households' dietary intake; and a dedicated section for gathering socioeconomic information. The articles presented in Chapters 4 to 6 are written based on the findings derived from this questionnaire survey. The original questionnaire used in the survey is provided as an appendix to the dissertation.

The article presented in Chapter 4 discusses the limitations of self-assessment recall questionnaires in quantifying household food waste, with a specific focus on underestimation. Additionally, the article explores and compares potential methodological approaches to address the underestimation error. A laboratory examination was conducted to simulate bread waste occurrence based on the consumers' bread consumption data obtained through the questionnaire survey. By utilizing statistical calculations to compare the questionnaire outcomes with lab measurement, the paper derives estimates of underestimation ratios and proposes calculation approaches that help reduce waste quantification errors, enabling more accurate estimation of the waste amounts. The primary focus of this chapter centers around addressing research objective 3.

The research paper featured in Chapter 5 offers a comprehensive exploration of household bread waste levels in Shiraz. In order to provide a more accurate estimation, the article adopts the methodological approach proposed in the preceding article found in Chapter 4. Moreover, the article incorporates a thorough review of previous reports and studies, thereby encompassing the broader context of household bread waste levels across Iran. By comparing the obtained results with previous findings, such as official reports and case studies, the article identifies variations and discrepancies, initiating a thorough examination of the reasons underlying such deviations. Additionally, the article investigates the factors contributing to the observed changes in household bread waste levels over time. This paper aligns with the objectives outlined in research objective 4.

The article outlined in Chapter 6 undertakes an in-depth analysis of the household bread waste level and its occurrence, exploring the influence of household dietary patterns and socioeconomic status. By utilizing multiple regression models, the article investigates the intricate links and identifies significant associations between these variables. Additionally, the article emphasizes the importance of implementing tailored food waste reduction measures that cater to the diverse needs and characteristics of different consumer groups. By acknowledging the factors that contribute to bread waste, such as dietary patterns and socioeconomic status, the article advocates for targeted interventions to achieve effective waste reduction outcomes. These interventions can take the form of targeted food waste reduction campaigns that specifically address the waste of specific food commodities within specific groups of household consumers. This research endeavor closely aligns with research objectives 5 and 6.

The general discussion outlined in Chapter 7 aims to thoroughly deliberate upon the peer-reviewed articles presented in this dissertation and the objectives delineated in the current chapter. By revisiting the overarching research objectives, the general discussion chapter highlights the effectiveness of the methodological approach employed in addressing each research objective. Furthermore, this chapter engages in a critical examination of the practical and methodological limitations encountered during the doctoral study, offering valuable insights for future investigations to consider. It also serves as an opportunity to synthesize the research findings, shedding light on their implications and significance. In addition, the chapter sets the stage for future research endeavors by providing directions and identifying important areas that merit further investigation. By drawing upon these findings, the general discussion chapter formulates meaningful conclusions that not only deepen our comprehension of the subject matter but also make valuable contributions to the broader knowledge base in the field.

The final chapter of this dissertation includes two additional scientific contributions presented at international conferences that are relevant to the topic but not integral to its core. These contributions are presented in the form of abstracts, highlighting their key findings and implications. While they provide valuable insights into related areas of study, they serve as supplementary components to the main body of research presented throughout the dissertation. Furthermore, following this chapter, the questionnaire employed in the second survey is provided, aiming to enhance transparency in research and offer support to fellow researchers in their future investigations. By including the questionnaire used in the second survey as Appendix 1, it is hoped that other researchers can benefit from its structure and methodology, fostering collaboration and advancing knowledge in the field.

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Chapter 2: Article 1

Title of the Article: Identifying Loss and Waste Hotspots and Data Gaps throughout the Wheat and Bread Lifecycle in the Fars Province of Iran through Value Stream Mapping

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Abstract

Reducing wheat and bread loss and waste is crucial for ensuring global food security and sustainability. The importance of reducing wheat and bread loss is particularly significant in Iran, where wheat is a staple crop and a vital component of the country's food security. A value stream mapping study was conducted to identify loss and waste hotspots and critical data gaps along the wheat and bread lifecycle (WBL). In October 2018, 14 experts were surveyed in Fars province, Iran's second-largest wheat producer. The study presents a detailed cradle-to-grave overview of WBL and identifies farms, foodservice, and households as the loss and waste hotspots. The results revealed significant data gaps regarding on-farm wheat loss and household bread waste. Additionally, although data exist in other segments of WBL, they are not readily accessible nor utilized to report loss and waste, highlighting the need for transparency within the WBL system and further research to compile existing data and analyze wheat and bread loss and waste. Other researchers can employ the holistic approach of the present study to investigate loss and waste throughout the lifecycle of other food items in different geographical contexts. The methodology adopted in this study offers advantages for defining the scope of research in lifecycle assessment and circular economy studies.

Keywords: food loss and waste; holistic approach; lifecycle assessment; lifecycle analysis; missing data; cereals; developing country

1. Introduction

1.1. Problem Statement and Objectives of the Study

Reducing food loss and waste (FLW) is crucial to achieve sustainable development goals and can address food security, mitigate climate change, improve economic growth, and preserve natural resources [1–8]. Among all food items, reducing waste and loss of wheat and bread is particularly important due to their essential role in providing sustenance to a significant portion of the world's population. Wheat is among the four main crops that account for half of the global production of primary crops [9]. Wheat is an important source of protein, fiber, and other essential nutrients that are necessary for maintaining good health, providing a significant source of calories and nutrients for millions of people [10]. In addition to the nutritional benefits, wheat and bread play an important cultural and social role in many societies [11]. Moreover, wheat has important industrial implications, such as in manufacturing food additives and as a feedstock for green chemistry [12].

According to the Food and Agriculture Organization (FAO) [13], in 2020, global wheat production reached over 760.9 million tonnes, accounting for over 8% of the total global crop production. The global wheat flour market is forecasted to expand from USD 160.66 billion in 2021 to USD 210.77 billion by 2028 [14]. Moreover, wheat and bread production has a considerable carbon footprint, and reducing their loss and waste can help mitigate the greenhouse gas emissions associated with their production and transportation, making it an essential step toward combating climate change. Safa and Samarasinghe [15] found that total CO_2 emissions from wheat production in Canterbury, New Zealand were 1032 kg CO_2/ha. In a study in southern Italy, Bux and Amicarelli [16] found that the primary production of durum wheat is responsible for the emission of 399–441 kg CO_2/ha and 339–374 kg CO_2/ha in conventional and organic farming, respectively. A lifecycle assessment (LCA) study on 21 different types of bread consumed in the European Union found that the global warming potential of 1 kg of bread ranges from 0.5 kg CO_2eq/kg to 6.6 kg CO_2eq/kg [17]. A study conducted by Chiriacò et al. [18] revealed that the carbon footprint of 1 kg of wholemeal bread was between 1.18 kg to 1.55 kg CO_2eq.

Iran is a major wheat producer, providing income and employment to millions in its agricultural sector. The wheat production of Iran in 2020 reached 15 million tonnes (ranking 13th globally), which comprised around 20% of its total crop production of 74.4 million tonnes, whereas the country imported 1,181,600 tonnes of wheat and did not export any [13]. This underscores the critical role of wheat in sustaining Iran's domestic food supply and supporting its agricultural sector. Around 43% of the agricultural lands in Iran are occupied for wheat production, accounting for over 55% of the arable lands used for the production of annual plants [19]. The total greenhouse gas emissions of rainfed wheat production in Kohgilouye Boyer-Ahmad province in southwestern Iran was estimated at 280.57 kg CO_2eq/ha by [20]. A study in

Bojnourd in northeastern Iran revealed that the production of 1 kg of irrigated and rainfed wheat is responsible for 1.22 and 0.72 kg CO_2eq, respectively [21].

Wheat and bread are subject to significant levels of loss and waste throughout the food supply chain. After fruits and vegetables, cereals (including wheat), with around 30%, have the highest share in global FLW [22]. However, data on FLW are often scarce, incomplete, or inconsistent, especially in developing countries [23,24]. The availability of accurate data on FLW is essential to develop effective strategies and measure their impact [25,26], as well as to raise awareness among stakeholders and consumers [27]. In a country such as Iran, where the reliance on wheat as an essential staple commodity is high, and its production has a significant environmental impact, there is an urgent need for accurate quantification of loss and waste along the wheat and bread lifecycle (WBL) to plan more effective measures to reduce them and increase production efficiency. It is, therefore, necessary to first recognize the structure of WBL through a holistic approach, pinpoint where loss and waste occur the most, and identify gaps in available data and knowledge.

Fars province is one of Iran's major wheat production regions and is essential to the country's overall wheat and bread industry. Located in southwest Iran, Fars province has a favorable climate and fertile soil well-suited for wheat cultivation. Fars province is responsible for producing a significant portion of Iran's wheat. Despite being ranked 11th in terms of the area under wheat cultivation, Fars is the second-largest wheat producer across Iran's 31 provinces, with an annual production of about 1.2 million tonnes, accounting for over 8% of the total wheat production [19]. Therefore, understanding the extent and causes of wheat loss and waste in Fars province can help inform targeted interventions and policies aimed at reducing these losses and promoting more sustainable wheat production practices. With its significant contribution to wheat production in Iran, Fars province holds great potential to influence the country's food security; hence, a thorough examination of loss and waste throughout the WBL in this region is essential.

This study adopts a qualitative approach to map the WBL in Fars province with a cradle-to-grave perspective, aiming to identify gaps in data and knowledge. By examining various stages of the WBL, including production, processing, distribution, consumption, and disposal, the study aims to identify areas where loss and waste occur, as well as to explore their underlying causes. Furthermore, the present study intends to investigate how material flow data at each WBL stage are recorded, as well as to evaluate their potential availability for calculating loss or waste at each stage. This study implements value stream mapping (VSM) methodology to provide a detailed understanding of the complexities of the WBL in Fars province to address the research objectives. The study's findings are expected to provide valuable insights into which areas necessitate additional research and where quantification of loss and waste amounts is required.

1.2. The Background and Implications of Value Stream Mapping

In order to prevent the omission of significant food industry stakeholders, it is crucial to adopt a holistic perspective of the food lifecycle and implement mapping approaches that address FLWin a comprehensive and integrated manner [28]. VSM is a lean manufacturing tool used to visualize the flow of materials and information within a production system, providing a holistic yet detailed perspective [29]. However, in recent years, the application of VSM has been extended beyond the realm of manufacturing to include the analysis of supply chains and products' lifecycles [30,31].

VSM approaches are also increasingly used in LCA studies to evaluate the environmental and economic impacts of FLW. Vinodh et al. [32] and Hartini et al. [33] have proposed practical frameworks for integrating LCA and VSM to identify activities and sources of problems in terms of economic, environmental, and social aspects. Salvador et al. [34] presented a similar model that prioritizes action measures based on environmental preference, economic feasibility, and ease of implementation. VSM provides vital information required for goal definition, scope design [35], and the assessment of environmental impacts in LCA studies [36]. Moreover, integrating VSM and LCA provides decision-makers with an accurate perspective, allowing them to prioritize action measures to adopt more environmentally friendly and economically viable practices [34].

VSM has implications in circular economy studies as well. Circular economy studies focus on reducing, reusing, and recycling materials to maximize efficiency, minimize waste, and promote sustainability [37]. Using VSM, researchers can identify areas where materials are being wasted or inefficiently used, allowing for targeted interventions to improve the circularity of a system [38]. For example, Galvão et al. [39] implemented VSM to propose a circular business model framework that connects value streams within circular business models and their ecosystems. Mangers and Plapper [40] introduced a novel VSM model that takes a holistic approach to assess interrelated processes and identify barriers to achieving a circular flow of resources.

Adopting VSM in agri-food studies and FLW research carries significant implications. A holistic view of the food lifecycle through VSM recognizes the complexity of FLWthat involves multiple actors, stages, and factors [41], enabling coordinated and collaborative efforts from different stakeholders [42]. In a systematic review, Steur et al. [43] found that VSM is a tool well-suited to identify and reduce FLW at different stages of food supply chains. An extended version of VSM was suggested by Bait et al. [44] to aid in the development of simulations for assessing management decisions on waste reduction. Kazancoglu et al. [45] utilized VSM to observe the material flow in turkey meat production in Türkiye to explore loss and waste drivers. In a study in Zimbabwe, Goriwondo et al. [46] demonstrated how VSM can be used to reduce bread waste.

Implementing VSM can help identify the different stages, causing factors, and their interactions that contribute to FLW, as well as the most effective entry points for interventions [43]. Portraying various stages of the food lifecycle through VSM allows for identifying areas where data is missing or incomplete [47] and prioritizing research efforts to fill these gaps. Furthermore, the ability of VSM to depict the intricacies of the food lifecycle enables improved development of FLWscope and definitions based on standardized global classifications [48]. This mitigates the issue of data incomparability, which primarily arises from variations in food lifecycle structures across different geographical contexts [49].

2. Materials and Methods

2.1. Sampling Strategy and Survey Development

The survey was conducted in October 2018, and judgmental sampling was used to select information-rich individuals who were actively engaged as actors in WBL. This sampling strategy was chosen because it allows for selecting individuals with the most relevant expertise and knowledge in the subject of study and also helps ensure that the key actors involved at every stage of the process, in this case, WBL, are included [50]. A total of 14 participants attended the interviews voluntarily and were informed at the onset that their data would be treated confidentially and that the results would be reported anonymously. Nonetheless, none of the practitioners employed at milling factories were willing to participate in this survey. The study intended to include the bakeries that produce the most commonly consumed wheat bread in Iran, chosen based on the food guidelines of the Iranian National Standardization Organization (INSO) [51,52]. The bread types are classified into two groups: traditional bread, with lavash and sangak being the most widely consumed types [11,53], and non-traditional bread, which include bulky oven bread types such as baguette, hamburger bun, sandwich, bread roll or broetchen, toast, and non-traditional barbari. Detailed characteristics and specifications of these bread types are provided by Ghaziani et al. [53], INSO [51,53], and Karizaki [11]. Table 1 anonymously lists the participants based on their role in WBL. Hereafter, the participants will be identified by their IDs from Table 1 to maintain confidentiality. For instance, the participant who held the chief executive officer (CEO) position at the local agricultural cooperative will be referred to as Co-op CEO.

Table 1. List of participants according to their professional roles.

Participant's ID	Role
Seed producer	The owner of a plant breeding and seed production company
Farmer 1	A farmer with large-sized (over 70 ha) land
Farmer 2	A farmer with small-sized (10 ha) land
Farmer 3	A farmer with small-sized (10 ha) land
Farmer 4	A farmer with small-sized (20 ha) land
Co-op CEO	The chief executive officer (CEO) at a local agricultural cooperative and a farmer with a medium-sized (50 ha) land
GCCS inspector	The technical inspector of Grain Company and Commercial Services (GCCS) of Fars province
Agri. Mins. Officer	A high-ranking officer at the Ministry of Agriculture
Foodservice 1	The owner of a fast-food restaurant
Foodservice 2	The head chef at a hotel
Baker 1	The manager of a traditional bread (sangak) bakery
Baker 2	The manager of a traditional bread (lavash) bakery
Baker 3	The manager of a traditional bread (sangak) bakery
Baker 4	The owner of a non-traditional bread bakery

The framework presented in Figure 1 provided a step-by-step guide for conducting interviews to gather detailed information about WBL. The interview framework was developed following the cradle-to-grave approach recommended in the FAO's 2013 report on the environmental impacts of FLW [22] to ensure comprehensive coverage of all stages of WBL. Additionally, the questions were conceptualized through consultations with a senior agronomy scientist from the region and the director of the Department of Cereal Production at the Agricultural Organization of Fars.

Value stream mapping

Q: Please expand on your understanding of the entire wheat and bread lifecycle.
Q: Where does the wheat material come from before your lifecycle segment?
Q: What happens to products after your lifecycle segment?

Loss and waste hotspots

Q: At which points of the lifecycle is wheat lost, or is bread wasted the most?
Q: What are the main reasons for loss and waste at these points?

Material flow inventory

Q: At which points of the wheat supply chain are material flow inputs and outputs measured/ recorded?
Q: Are you obliged to report the material flow inventory to any organizations or authorities?
Q: How and where are the material flow inventory data stored?

Waste management

Q: How do you manage wheat or bread loss and waste?
Q: What do you know about what would eventually happen to the lost wheat material or wasted bread?

Figure 1. Interview framework; Q = question.

As the first step of the interview framework, VSM was applied to map WBL based on a contextual modification of the diagramming method described by Pretty et al. [54]. Accordingly, participants were given drawing supplies to interactively develop a value stream map representing the WBL in Fars. The map was created on a large sheet of paper, and participants were encouraged to use different colors to highlight the various stages of WBL. Specifically, the drawing exercise aimed to illustrate the processes and material flow involved in the cultivation, harvest, transport, storage, milling, baking, distribution, and consumption of wheat and bread in Fars. Follow-up questions were also asked to clarify and complement the information regarding the structure of WBL. The final value stream map presented in Section 3 was the result of merging the individual diagrams.

Furthermore, open-ended questions were asked to identify loss and waste hotspots, as well as to collect information about the material flow throughout WBL. Specifically, the questions were intended to determine how material inputs and outputs were recorded at each WBL stage and evaluate the potential availability of data for calculating loss and waste. Additionally, the questions aimed to investigate how the loss or waste materials were handled and to uncover the destination of materials designated for disposal. In this study, the term ‘material’ is defined as referring specifically to wheat and bread and excludes any other substances or matters. Examples of questions asked at different steps of the interviews are provided in Figure 1. The interviewers encouraged active engagement from the participants during the discussions, allowing them to argue and elaborate on their responses.

2.2. Data Analysis

The qualitative open-ended survey data analysis explained by Fielding et al. [55] was implemented to systematically code and analyze the interview transcripts using MAXQDA software [56]. MAXQDA is designed to aid researchers in analyzing qualitative data, such as interview transcripts, survey responses, and open-ended survey questions. The software offers various functionalities and benefits, including the creation of codes, categories, and themes to identify patterns and relationships within the data. By utilizing both manual codings by the researcher and automated codings via natural language processing algorithms, MAXQDA enabled an efficient and effective analysis of qualitative data, uncovering essential patterns and themes related to WBL. The participants’ statements during the interviews were considered a direct representation of their understanding of the questions. Any quantitative information provided by the interviewees was excluded from the study with the assumption that the sample is not representative of the stakeholders in WBL. The interviews were transcribed and translated from Persian to English by the first author, and structural coding was applied to the participants’ answers based on the interview framework (see Figure 1). The creation of sub-codings continued as long as no new classification could be found.

3. Results and Discussion

3.1. Overview

In this section, the outcomes of the interviews are presented within the survey framework and discussed against the existing research on wheat production and FLW. The results are presented as an interpretation of the participants' statements, along with direct quotations of their answers. The procedures explained in this chapter summarize the participants' responses. Complementary information is cited from the literature. The first subsection provides detailed information about the WBL and material flow in Fars province. The following subsections expand on the hotspots of wheat loss and waste, material flow data inventory, and the availability of loss and waste data at different segments of the WBL in Fars.

3.2. Wheat and Bread Lifecycle

Figure 2 demonstrates a schematic overview of material flow and production process throughout the WBL in Fars province. The following subsections present a cradle-to-grave description of WBL, explaining the details of Figure 2.

The Agricultural Research, Education, and Extension Organization (AREEO), a sub-branch of the Ministry of Agriculture, is responsible for seed certification and supplying seeds to wheat producers [57]. AREEO produces the nucleus breeds for private breeding companies to cross-breed and produce hybrid cultivars and, eventually, certified seeds [58]. The seeds obtained from the propagation of hybrid cultivars are called certified seeds and are the last class of seeds in the seed certification program [59].

"Until 12 years ago, AREEO used to produce certified seeds. Nowadays, AREEO focuses only on research and producing nucleus breeds and delegates the rest of the breeding program to private companies…. We recently received breed 2, from which we produced 60 kg of breed 3 and, finally, 200 kg of the maternal line. Certified seeds are produced by [propagating] maternal seeds." (Farmer 1)

Certified seeds are available to farmers in large quantities for the mass production of bread wheat [59]. Bread wheat refers to the product that is eventually used to produce bread. The supply of certified seeds is essential for ensuring high productivity, particularly in small-scale farms [60].

"We plant certified seeds supplied by AREEO. We purchase the seeds from the local AREEO subsidiary." (Farmer 4)

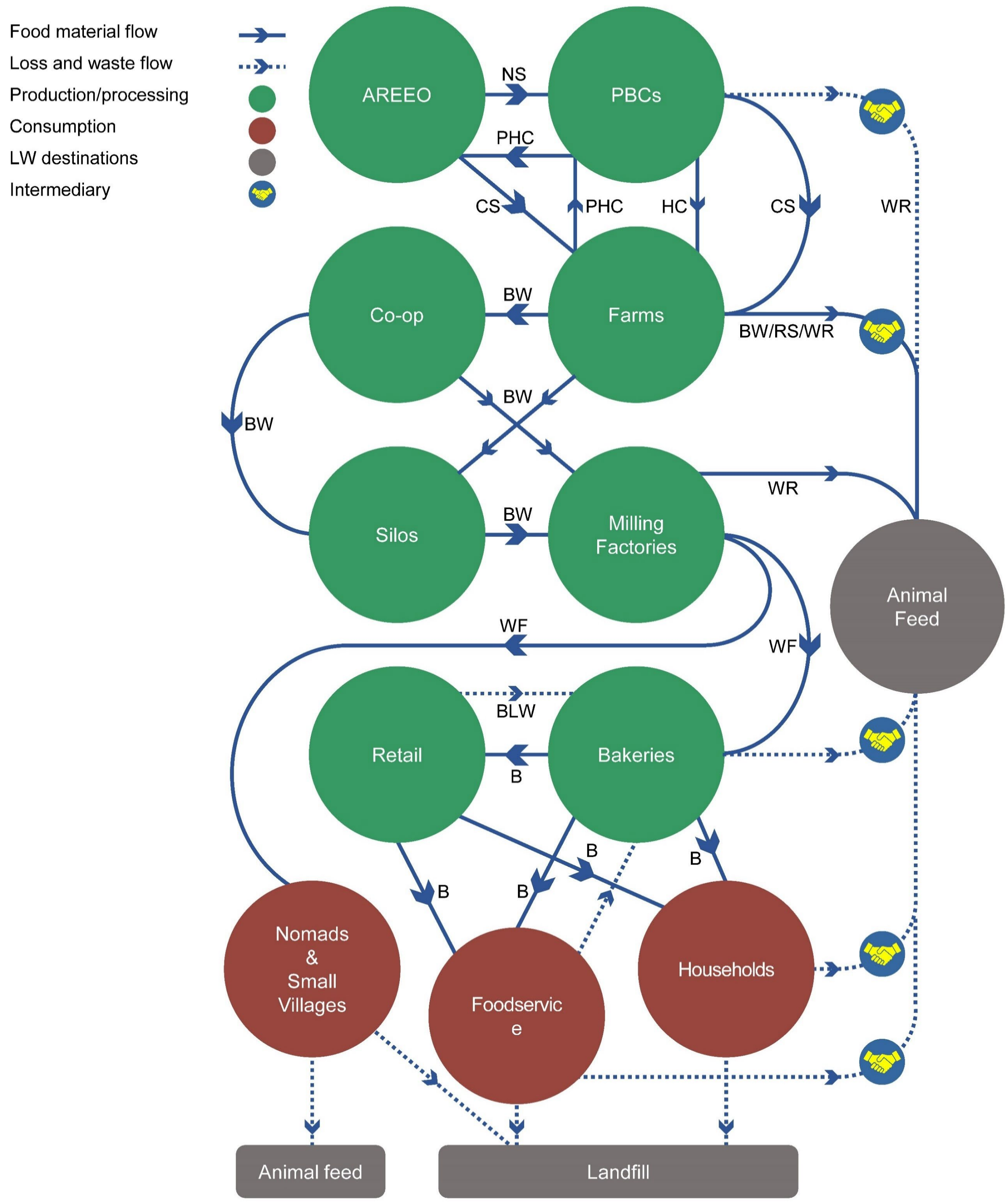

Figure 2. Schematic presentation of wheat and bread lifecycle in Fars province. NS = nucleus seed (the best quality seed with high genetic purity used as the foundation for producing subsequent generations of seeds); HC = hybrid cultivar (produced by crossing two or more genetically distinct nucleus parents to create offspring with desirable traits); PHC = propagated hybrid cultivar (seeds that are produced abundantly by propagating hybrid cultivars); CS = certified seed (propagated hybrid cultivar seeds after being winnowed and threshed, and then treated with pesticides and fungicides, and officially certified); WR = winnowing residues (the byproducts left after winnowing wheat); BW = bread wheat (wheat intended for bread production); WF = wheat flour; B = bread.

The private breeding companies outsource part of the seed production program to selected farms with facilities suitable for seed production. This procedure is commonly known as contract seed production and is used to ensure that the seeds are produced in large quantities and meet the certification standards [61]. One of the potential benefits of contract seed production is the emergence of participatory plant breeding (PPB), a system that involves the direct engagement of farmers in the breeding procedure [62].

"The seed-producing companies sign contracts with some farmers. They give maternal seeds to farmers, and farmers produce certified seeds. The certified seed is used to produce bread wheat." (Co-op CEO)

Contract seed production provides farmers with outstanding performance with the opportunity to earn extra money. Additionally, PPB leads to increased efficiency and societal benefits [63,64]. By working together with farmers and incorporating their feedback, breeders can create new varieties that are well-suited to local conditions and fulfill the requirements of both farmers and consumers [65]. The farmers produce seeds by propagating hybrid cultivars and sell them back to breeding companies or AREEO at a higher price than bread wheat.

"We produce two types of wheat: one for seed using the hybrid cultivars supplied by breeding companies and another for consumption produced from certified seeds.… The price of the seeds is normally 20–25% more than bread wheat" (Farmer 1)

AREEO selects farmers who meet the criteria after inspecting their farms and provides instructions to produce seeds. This process ensures that the seeds produced meet the required quality standards [66].

"The cultivation for seed production is executed more carefully compared to bread wheat. For example, AREEO requires farmers to test the soil for efficient fertilization." (Co-op CEO)

The farmers return the seeds to private companies or AREEO. The companies or AREEO grade a seed batch based on the besatz content and pay the farmers accordingly. According to the International Association for Cereal Science and Technology (ICC) [67], the besatz of wheat refers to any material in a wheat sample other than the intact, perfect grains. The Iranian authorities use the same grain grading system [68,69]. The two classifications of besatz of wheat are grain dockage and black dockage, also known as useful and non-useful Besatz [67]. Grain dockage includes the undesirable forms of wheat grains, e.g., broken, shriveled, sprouted, damaged, or grains of other varieties or crops [67]. Any other extraneous material and impurities, such as weed, ergot, soil, chaff, and straws, are known as black dockage [67]. The seeds that do not meet the minimum quality criteria regarding besatz will be rejected and sold as animal feed.

"If the seeds produced by farmers contain high soil and weed dockage or too many broken grains, the companies or AREEO reject them, and farmers sell them as normal wheat." (GCCS inspector)

Traditionally, farmers used to produce their own seeds, but currently, they prefer to purchase high-performance certified seeds.

"I purchase the certified seeds distributed by the rural cooperative. My father used to reuse the good wheat grains as seeds for the next year's cultivation. Or if a neighboring farmer had good seeds worth more than bread wheat, my father used to make a deal with them to replace their good batch with bread wheat and get their good seeds for cultivation. The other farmer was selling the bread wheat batch at a normal price, and my father would pay them the difference. The good grains were sprayed with a certain pesticide and stored to be used as seeds in the following year. I do not do that." (Baker 3)

Moreover, because seed production requires extra attendance, not all farmers are willing to participate in the seed production program.

"I could also produce seeds, but they [breeding companies or AREEO] do not buy them because they [the seeds] include too much soil and weed impurities." (Farmer 3)

AREEO certifies the seeds after they are threshed and sprayed with pesticides. This seed treatment helps to prevent pests and diseases from infecting the seeds and the young plants that emerge from them, preventing yield and quality loss [70]. The residues derived from the threshing, e.g., broken seeds, straws, leaves, and weeds, are sold as animal feed through intermediaries. Intermediaries are private buyers who purchase agricultural products or byproducts at a negotiated price and sell them to other parties, usually to feed factories or livestock farms. By linking smallholder farmers with traders and feed markets, intermediaries can help improve farmers' commercialization opportunities while utilizing byproducts that are unsuitable for human consumption, leading to reduced biomass loss [71]. These intermediaries purchase not only threshing residues or uncultivatable seeds but also bread wheat. However, the primary buyer of the bread wheat is the government through agricultural cooperatives. Oligopolistic state trade of wheat is also common in other countries, such as Ethiopia [72], China [73], Kazakhstan, and Russia [74].

Farmers cultivate wheat in the Fars region through rainfed or irrigation. Their chosen method depends on the available water resources, such as a well, qanat, spring, or dam.

"Farmers usually do not irrigate the field if it rains about 30–40 mm after sowing." (Co-op CEO)

The farmers sow wheat at the end of summer (around September and October) and irrigate the land until two to three weeks after germination at the beginning of winter and before the dormancy starts. Dormancy is a survival mechanism that refers to a period of reduced metabolic activity and growth, which enables the plant to conserve resources until environmental conditions allow for resuming growth and development [75]. The crops enter their vegetative phase as the weather warms up at the end of February. At this stage, pesticide implementation and fertilization occur at intervals of a few days. Nitrogen fertilizer should be applied after dormancy in order to achieve optimal yield and protein levels [76]. Farmers again irrigate the land if the precipitation is inadequate before they harvest the crops at the beginning of summer, around mid-June and July.

"We harvest [wheat] in June or July." (Farmer 3)

Once harvested, the wheat is transported to agricultural cooperative purchasing centers. From there, it is shipped to government-run storage facilities, i.e., silos.

"We sell our [wheat] products to the cooperative, and they send them to silos." (Farmer 2)

Depending on the logistics, some farmers may ship their products directly to silos.

"We sell the product directly to silos. Sometimes we sell to the cooperative." (Farmer 3)

"We deliver the yield to the cooperative." (Farmer 4)

The cooperatives and silos test the purity of wheat grains to determine the price based on the purity table. The purity table indicates wheat prices according to the besatz content and sunn pest-damaged grains using random sampling by grain spears [68,69]. Sunn pests include a number of insects belonging to the sub-order Heteroptera, which have been identified as a severe threat to wheat and other cereals in the Near and Middle East and a large portion of the former Soviet Union [77]. The presence of sunn pest-damaged grains in a wheat bulk, even as low as 2%, causes a decline in the physical, chemical, and technological quality of wheat [78]. After quality evaluation, cooperative purchasing centers or silos weigh the delivered wheat cargo and issue a payment remittance.

"The wheat is delivered to the cooperative's purchasing center. It is weighted here, and the amount is recorded in the online system under the farmer's name. The online system is connected to the Keshavarzi Bank (Bank of Agriculture), GCCS, and the Ministry of Industry, Mine, and Trade." (Co-op CEO)

"The cooperative records the yield. They also assess the besatz content to determine the price based on their tables. They give us a receipt with all the details and record everything on a computer." (Farmer 4)

The cooperatives are public joint stock companies with a stewardship contract with GCCS. Each cooperative is run by its members, who are usually the farmers in a distinct region.

"Our cooperative has 2000 members (shareholders) from 14 surrounding villages." (Co-op CEO)

These cooperatives are responsible for testing and delivering wheat, storing and safekeeping it, and shipping it to silos or milling factories, depending on the orders from GCCS.

"From the moment producers deliver wheat to us, we are responsible for storing and safekeeping the wheat and later loading trucks and sending it to its designated destiny, which GCCS of Fars [province] determines. The destinations can be a milling factory or a silo…. GCCS uses an online system to tell us where to distribute wheat." (Co-op CEO)

The government pays the total value of the wheat cargo to the farmer. The Council of Pricing and Implementation of Supportive Policies for Basic Agricultural Products of the Ministry of Agriculture annually determines the procurement price for wheat—which literally translates to "guaranteed price"—before each cultivation season [79]. Wheat procurement price refers to the price at which the government or authorized agencies commit to purchase wheat from farmers [80]. Such a trading strategy has also been implemented in other countries such as Egypt [81], Pakistan [82], and India [83]. Implementing procurement prices can improve the economic situation of farmers and promote agricultural productivity [84]. However, the impacts of procurement price may vary depending on a range of factors, such as the design and implementation of the policy, the specific crop and region, and the economic context [85]. Therefore, policymakers must carefully evaluate the potential trade-offs before determining prices and contractual terms.

After farmers deliver the wheat they harvested to the purchasing centers, it may take up to three months for them to receive payment.

"The payment takes around two months. I sold my last batch at the end of June 2018. The payment took two to three months." (Farmer 3)

Cargos with besatz and sunn pest-damaged grains more than the maximum legally tolerated level determined in the purity table and water content higher than 12%—with the exception of distinct humid regions, in which the limit is 14%—are rejected [68,69]. Wheat grains with high moisture content are prone to fungal infection [86]. Wheat storage for up to nine months requires a maximum moisture content of 14%, while for longer-term storage exceeding nine months, the moisture content should not exceed 12% [87]. Assuring the quality of wheat that enters the human consumption chain is crucial for maintaining high technological performance while protecting consumer health, sustaining international trade relationships, improving market competitiveness, and promoting agricultural productivity [88]. Farmers sell the wheat rejected due to quality reasons as animal feed through intermediaries.

As mentioned before, farmers may also sell bread wheat as animal feed to intermediaries besides the cultivation byproducts, e.g., chaff and straw, and seeds or wheat gains rejected due to lack of quality.

"Not all the wheat the farmers produce is purchased by the cooperative. Some private buyers pay a negotiated price to the farmers…. These buyers either sell to the milling factories or the silos." (Co-op CEO)

"Some intermediaries buy [bread] wheat to sell to the livestock feed-producing factories or directly to livestock farms. They normally have storage and weighing facilities." (Farmer 2)

Using wheat as animal feed can negatively affect food security by decreasing food availability and increasing food prices [89]. On the other hand, using wheat byproducts for animal feed, such as middling, can have some positive outcomes, including reduced CO2 emissions due to the shift of application [90]. The incentive for selling bread wheat to intermediaries is mainly economic. Transacting with intermediaries is less time-consuming than with the government.

"They [intermediaries] normally pay less than the government, but they pay right away." (Co-op CEO)

"[With intermediaries,] there is no waiting time to weigh farmers' products, and the payment is instant, although at a bit lower price." (Farmer 2)

Although negotiated price usually is less than the government's procurement price, depending on the market climate in the feed industry, intermediaries may sometimes pay more than what the government pays for bread wheat.

"[Currently,] intermediaries pay more than cooperatives or silos…. They sell the wheat for livestock feed at a slightly higher price." (Farmer 3)

Although procurement price is fixed and controlled by the government, because animal feed is traded in a free market, animal feed prices fluctuate depending on supply and demand, weather conditions, government policies, transportation costs, and global market trends. That is why farmers would sometimes benefit more if they sell their products as animal feed.

Despite the procurement price being fixed and regulated by the government, animal feed prices remain subject to free market fluctuations. In a free market, food and feed prices are constantly changing due to factors such as supply and demand, weather conditions, government policies, transportation costs, and global market trends [91]. As a result, farmers may benefit more by selling their products as animal feed. Therefore, some farmers may retain part of their harvested wheat to later sell at a higher price to intermediaries.

"Normally, farmers sell wheat to silos or the cooperative right after harvest. They also store part of their harvest, which they later sell to intermediaries for livestock feed. Some farmers build a storage room, usually made of cement and isolated with tiles from the inside." (Farmer 3)

Nonetheless, farmers sell most of their wheat to the government. One reason is that not all can afford a storage room, and the on-farm storage rooms have relatively limited space. A suitable storage room for wheat must have regulated temperature and humidity, along with appropriate ventilation and isolation, to prevent insects and animals from damaging the wheat [92]. Due to the demanding and complex nature of wheat storage, most farmers tend to sell their wheat to the government once it is harvested to reap some economic gain, despite the delayed payments.

"Almost 90% of the farmers are not able to store their yield. Therefore, they need to sell their product as soon as possible to gain some revenue to compensate for their costs for at least nine months." (Co-op CEO)

Moreover, farmers can benefit from governmental support for the upcoming cultivation season based on their last season's performance.

"The advantage of selling to silos or cooperatives is receiving subsidized seeds, fertilizers, and pesticides. Moreover, our personal storage room is limited." (Farmer 3)

"It is sometimes better to sell to the cooperative [or to silos] because we can buy fertilizer and pesticides with a discount for the next year in proportion to our current harvest amount." (Farmer 2)

Additionally, although regulations change according to circumstances, farmers may be legally obliged to sell their wheat only to the government during certain times.

"[Currently,] supplying wheat outside the governmental supply chain is against the law, even to individuals." (GCCS inspector)

Wheat is stored at the cooperative's purchasing centers for a relatively short time and shipped mainly to silos and, as explained before, sometimes to milling factories.

"We receive wheat starting from June 10 until around July 1. We store the wheat (about 6000–8000 tonnes) here, usually around 20–30 days. In rare cases, we store wheat here for up to three months." (Co-op CEO)

Afterward, wheat is stored in silos and supplied to milling factories, depending on the demand.

"Wheat remains in silos and will be distributed based on demands throughout the year. The silos are organized by the government." (Co-op CEO)

Silos are proven to be the best means of wheat storage [93]. GCCS is the custodian of silos and is responsible for supplying wheat to milling factories through an online platform.

"The GCCS of Fars uses the online system to tell us how to distribute wheat. For example, the GCCS of Fars would give us transportation permission for shipping 2000 tonnes of wheat to [company's name] milling factory." (Co-op CEO)

Milling factories store wheat and gradually process it over the course of a year. The wheat in silos includes besatz and needs to be threshed at milling factories. The threshing residues are sold to intermediaries for animal feed.

"The grains in silos are not threshed and include soil and weed residues or broken grains." (Farmer 1)

Milling factories grade the wheat grains based on their quality and pack them for shipment. Wheat grading is determined by factors including test weight, moisture content, protein content, foreign material, damaged kernels, and other relevant characteristics [94]. GCCS, together with the Bakers Union, are responsible for setting wheat flour quotas for bakeries based on their needs and production outcome. Milling factories ship the bakeries' flour quota over time. All such transactions are executed through the GCCS website.

"Milling factories separate the bran from the grains and grade them based on the existing standards. These factories distribute wheat flour to local or industrial bakeries based on quotas designated by GCCS Fars province and the union of bakers." (Farmer 2)

"The government controls the distribution through an online platform, and bakers receive wheat flour based on their quota.… Our baking factory produces up to one thousand bread pieces per day. This amount is produced from our wheat flour quota." (Baker 4)

"We order online based on our quota. The milling companies ship flour to each bakery based on online orders. We also pay transportation costs and store flour here." (Baker 3)

"We order wheat flour via a website. Each bakery has a quota for each month. We store the flour here and prepare the dough, and then bake the bread." (Baker 1)

The use of digital platforms within the WBL in Fars has the potential to not only increase overall efficiency but also enhance food traceability, contributing to food safety and improved economic transparency [95]. Additionally, the digitalization of food supply chains allows for identifying the hotspots of FLW and reducing it [96].

Milling factories may sell their surplus production through the free market.

"The milling factories supply wheat flour either to the free market via whole sellers or directly to bakers." (Baker 4)

Parts of the flour are shipped from the milling factories to nomads and small villages in the neighboring region for their consumption.

"The nomadic families and households in small villages also have flour quotas to bake their own bread." (Farmer 2)

Bakeries produce bread and supply it to end consumers via foodservice or supermarkets or directly to households.

“Our buyers are supermarkets, household consumers, and fast food stores…. We sell bread to supermarkets in dated plastic packs…. Household consumers and fast foods buy fresh bread daily.” (Baker 4)

In the event that the dough is ruined, the bakers repurpose it into dry bread, which they then sell to intermediaries as livestock feed.

Foodservice enterprises purchase from different types of bread producers based on their needs.

“We have a contract with an industrial bakery. The bread comes daily in box packs of 40 pieces.” (Foodservice 1)

“We buy our bread from a local bakery…. We use the fresh bread for the day and store the surplus in a freezer.” (Foodservice 2)

3.3. Loss and Waste Hotspots and Data Gaps

This subsection outlines details on the hotspots of loss and waste, along with the availability of relevant data. The participants reported that loss and waste are likely to occur at each stage of WBL. However, the losses incurred at the stages between the farm and the retail stage are limited. On the other hand, significant losses and waste of wheat and bread occur at the primary production and consumption stages.

Wheat loss at purchasing centers, silos, and milling factories is kept to a minimum.

“The loss in the cooperative’s purchasing center is minimal. I am personally liable for any loss that may happen here…. Silos have a minimal amount of loss. For example, the nearby Silo in Sivand has a capacity of 70,000 tonnes. When the silo is fully loaded, it can preserve between 69,500 and 69,700 tonnes [about 0.07% loss]. The rest could rot or absorb too much moisture, which is insignificant.” (Co-op CEO)

“Once wheat enters milling factories, there is no loss. All parts of the wheat will be sold. For example, the wheat bran separated to produce white flour for confectioneries will be sold for animal feed.” (Farmer 1)

The main reasons for food loss at purchasing centers and silos may include inadequate management, inappropriate handling and storage practices, and restrictive regulations [97]. In the case of cereal grains, high moisture content and inadequate management practices can lead to substantial food loss in silos caused by mold infestation and in milling factories due to spoiled raw material [98]. However, high moisture content does not seem to be a significant issue in arid areas such as Fars province.

“The highest loss in storage can happen due to high water content, and because wheat has low water content in Iran, this loss is limited.” (Agri. Mins. Officer)

Under normal circumstances, the amount of wheat or bread lost during transportation between different lifecycle segments is negligible.

"Transport loss is limited unless the trucks are not sealed well, which does not happen often." (Farmer 4)

A study by Melese et al. [99] in Ethiopia revealed that there was a relatively small wheat loss (0.17%) during transportation from the farm to the threshing field. Additionally, according to the FAO [100], losses during the transportation of wheat do not exceed 1% due to well-sealed transportation containers and careful handling of the crops during transportation. According to a study by Łaba et al. [101] in Poland, 1.7% of the total cereal supply intended for human consumption was lost during transportation from the field to the purchase centers or processing units.

The interviewees employed at bakeries claimed that very little loss and waste occur at their workplace. The bakeries tend to repurpose expired or stall bread to avoid waste.

"We do not experience any flour loss, and we are able to sell all the bread we produce. However, if the dough is ruined, we have to convert it into dried bread and sell it to intermediaries who eventually sell it to livestock farms." (Baker 1)

"We usually sell 100% of our white bread production, although other bread types may experience some loss. During certain conditions, such as heavy rain or cold weather when we have fewer customers, we may not sell 100% of our production. Consequently, we end up with some unsold bread which we typically dry and sell as breadcrumbs." (Baker 4)

Likewise, the amount of bread waste at food stores and supermarkets is minimal, and bread products that pass their expiration date are sold as animal feed through intermediaries. Bread waste is often considered a potential livestock feed source due to its high carbohydrate content and availability in large quantities [102]. However, using bread waste as animal feed is not without its hazards. One of the main concerns is the potential presence of aflatoxins [103], which are toxic substances produced by certain types of fungi [104]. Aflatoxin contamination occurs in bread as a result of fungus growth [105]. The use of bread waste as animal feed in Iran has led to indirect contamination of food and animal products [106,107]. For example, Mokhtari et al. [108] detected levels of aflatoxin in milk distributed in northwest Iran that can pose a risk of liver cancer to consumers.

Aflatoxins are highly toxic and carcinogenic, and the ingestion of contaminated feed by animals can result in various health complications, and the potential transfer of aflatoxins to humans through contaminated animal-derived food products poses a significant health risk [109]. The toxic effects of aflatoxins can impair protein synthesis, coagulation, weight gain, and immunity, leading to further health complications [110]. Prolonged exposure to elevated levels of aflatoxin can lead to a progressive decline in health in humans and animals, resulting from liver damage and immune suppression [111]. In light of the foregoing, while utilizing bread waste as animal feed may promote the circularity of WBL, it also entails substantial health hazards and raises concerns about food safety. Therefore, careful monitoring and management are required to ensure that bread waste used as animal feed is free of contaminants and safe for consumption by livestock.

"The main reasons for bread loss in supermarkets are expiration date and stale bread. Supermarkets typically sell their bread waste to bread waste recyclers, who in turn sell it as livestock feed." (Baker 4)

Despite the limited loss and waste at the WBL stages mentioned above, participants identified farms, foodservice, and households as the major hotspots for wheat and bread loss and waste.

On-farm wheat loss is considerable, as stated by the participants, primarily due to the excessive use of seeds during planting, pest and weed infestation, and inefficient harvesting practices.

"The on-farm loss is due to seed overuse, pests and harvesting." (Seed producer)

Farms are a primary contributor to food loss due to inefficient cultivation, harvesting, and handling practices [112,113].

The results also showed that considerable food waste happens in the foodservice and hospitality sectors.

"Bread waste happens in restaurants due to consumers having leftovers or passing expiration dates and staling." (Baker 4)

Restaurants and other foodservice establishments generate a significant amount of waste, mainly due to their inefficient operating practices and policies, as well as social norms that lead to excessive purchasing and consumption of food [114].

The participants identify households as the primary point of bread waste along WBL.

"The highest bread waste amount is in households because the consumers do not manage their grocery shopping appropriately." (Baker 4)

It is well-established that households are among the biggest contributors to food waste [24]. However, due to its multifaceted complexity, household food waste cannot be attributed to a single factor [115]. These factors may include, among other things, packaging [116], food pricing and consumers' purchasing behavior [117], consumers' level of education and their awareness about sustainability attributes of food [118], households' dietary behavior [53,119,120], household's socioeconomic status [53], and consumption recipes [121].

Although the results presented here offer insight into the extent of loss and waste across various stages of WBL, they reflect subjective opinions from the participants. Hence, more precise quantification of these losses is necessary to efficiently monitor and implement loss and waste reduction plans. The following subsection examines the feasibility of measuring waste and wheat loss at different stages of WBL based on the availability of material flow data.

3.4. Material Flow Inventory along the Wheat and Bread Lifecycle

Using color codes, Figure 3 provides an overview of the level of data availability related to the inputs and outputs of wheat and bread across various stages of WBL. However, it must be noted that the data availability level only confirms the existence of the data in their raw form and does not necessarily imply their accessibility. All material flow data, regardless of availability levels, have primarily been recorded for bookkeeping and administrative purposes and, to our knowledge, have not been analyzed to calculate or report loss and waste. Moreover, quantitative material flow data could not be accessed for the present study due to restrictive data ownership policies. Therefore, this article solely relies on qualitative information from interviewees regarding documented data that are available for potentially reporting loss and waste. As a result, quantitative information about the amount of loss or waste cannot be provided with acceptable certainty.

In Figure 3, green marks indicate that data on the mass amount of wheat is available for individual farms, factories, agencies, or commercial units. This means that the amount of wheat produced or traded by these entities is known and recorded. Yellow marks on the figure signify that data on money transactions due to wheat trades are available for mass units of wheat, which can be converted to the amount. This means that while the exact mass amount of wheat produced or traded may not be known, the monetary value of the traded amount is recorded. The orange markings represent that data on monetary transactions resulting from wheat or bread trades is available, but the transactions do not seem to correspond clearly to the mass amount of wheat or bread. This suggests that although some information regarding monetary transactions of wheat production or trade is obtainable, determining the wheat mass amount may be unclear or complicated. The red markings indicate that data on wheat or bread's input or output quantity, or the monetary transactions resulting from their trades, are not obtainable. This suggests that there is a lack of information about the wheat material flow in these areas.

Figure 3. Data availability throughout the wheat and bread lifecycle in Fars province, Iran. [1] no valid data could be found regarding on-farm losses; [2] any movement of wheat and bread between lifecycle segments falls under the purview of transportation.

The study revealed that the material flow at seed supply, farms, purchasing centers, silos, milling factories, and transportation is well-documented and potentially available for calculating wheat loss. The records of material input at bakeries are also accurately recorded in the digital platform of GCCS. However, material output data is only available at bakeries based on the monetary value of bread units sold. The same applies to the material input and output at retail units and the input of foodservice. In the meantime, quantifying the amount of bread sold in the foodservice sector is challenging because bread is sold alongside other food items rather than individual units. Commercial entities also record their trades with intermediaries who act as food waste recyclers for bookkeeping purposes.

"We sell expired or stalled bread to intermediaries who sell them to animal farms as feed. We also record the amount we sell to them." (Baker 2)

"We record what we sell to bread recyclers for internal accounting." (Baker 3)

"We sell bread leftover to bread recyclers. They measure the amount and pay us accordingly." (Foodservice 1)

In the case of loss during production, although material flow is accurately documented, this information alone cannot be used to calculate the on-farm loss amount due to the multifaceted nature of crop production. The outcome of an arable farm depends on multiple factors besides the amount of seed input, including climatic conditions, geographical location, soil conditions, the availability of water, and the choice of plant variety [122]. On the contrary, the production output of a milling factory, for example, is directly proportional to wheat input, although the ratio may differ depending on the specific equipment and technology used in the factory [123]. Similarly, the amount of bread produced from a certain amount of flour is predictable at a bakery based on the baking recipe. Additionally, the acceptable loss level at storage or purchasing centers can be predicted unless an unexpected issue, such as fungal contamination, occurs.

The input and output of this purchasing center are accurately recorded. There is weight loss, which is due to losing moisture. We record moisture content both at purchasing time and later at loading time. [In the last measurement], the average moisture content of 12 random samples was 8.9%. The average at the time of loading was 8.1%, which means a 0.8% mass reduction was expected. (Co-op CEO)

The data on the amount of on-farm loss of cereals is scarce. According to the FAO's 2011 report [113], primary production accounts for approximately 2% and 5–7% of cereals lost in developed and developing countries, respectively. However, Johnson et al. [124] shrewdly observed that almost all reports on on-farm loss rely on approximate estimation without field-level measurement and, at best, are based on questionnaire results from farmers. Farmers' estimation of on-farm loss is often biased and inaccurate [125]. Furthermore, the data at the farm level often lack consistency and accuracy, which makes it challenging to compare and aggregate loss and waste figures across farms and regions [1,124].

The primary data gap exists at the household level, as the amounts of bread households purchase are not documented. Nonetheless, the average amount of bread households consume could be obtained on a regional scale based on macro data on bread supply or households' expenditure information. Yu and Jaenicke [126] utilized food acquisition data to estimate household food waste in the United States, revealing that food waste at the household level in the country is 31.9%. However, this method is subject to high uncertainty due to its reliance on approximations [24]. Additionally, reporting waste figures for individual food items or even food groups may not be feasible.

The only recent primary data collection on household bread waste in Iran was conducted by Ghaziani et al. [127] in the capital of Fars, Shiraz. The study found that 1.8% of the bread households purchase in Shiraz is wasted [127]. Nevertheless, this result may be underestimated due to the method used, which relied on recall questionnaires to determine household waste. Ghaziani et al. [121] carried out an additional study to identify a methodological approach to account for underestimation errors by comparing questionnaire results with lab measurements after replicating consumption recipes. Their research revealed that the estimated waste was underestimated by factors ranging from 1.24 to 1.80, indicating that an estimated bread waste amount of around 3.5% might be more accurate [127].

Generally, self-assessment methods such as recall questionnaire surveys may underestimate the amount of household food waste due to their reliance on individuals' perceptions [23,128–130]. In comparison, approaches that entail physically measuring household food waste may generate more reliable results [131]. Nevertheless, these methods are less commonly employed in practice due to their high costs and labor-intensive nature [132]. The only studies to have measured household bread waste in Iran were conducted by Mirfakhrayi et al. [133] in 1991 and Irani et al. [134] in 2005. The former estimated that 30% of bread was wasted in households, while the latter found that the amount of bread waste varied between 12–16%. Ghaziani et al. [127] compared their own findings with these two reports and explored potential explanations for the relatively large deviation. The possible reasons include differences in waste definitions and methodologies, changes in domestic storage practices, and increased access to freezers in households [127]. Additionally, the study discussed the impact of the 2019 recession on consumer purchasing power, which could have led to more frugal lifestyles and a reduction in food waste. Given the age of the previous estimates [133,134] and their large deviation from Ghaziani et al.'s [127] findings, conducting new research using accurate methods in other locations of the country is necessary to provide a realistic estimation of household bread waste in Iran.

3.5. Limitations of the Study and Future Research Directions

This study employed a judgmental sampling strategy to select participants with specific expertise and knowledge of the WBL in Fars. However, while judgmental sampling can be useful in certain research contexts, it is essential to be aware of its potential biases and limitations. Judgmental sampling can introduce bias and subjectivity due to conditional information search strategies, potentially leading to limited external validity, poor reliability, and non-representative samples [135–138]. Nonetheless, judgmental sampling is a useful technique in multifaceted situations where classical measurement theory assumptions are invalid, particularly in quality improvement studies [138], and can be more representative and accurate than probability sampling strategies when used by an authority with specialty knowledge [50]. It can also be a time- and cost-effective approach for selecting participants with the necessary expertise and experience [136,138]. Additionally, judgmental sampling can be the most suitable and efficient approach when the objective is to learn about a specific process [138]. Considering that the objective of the present study was to understand the intricacies of WBL and identify areas that require further research and quantification of loss and waste amounts, judgmental sampling was employed as an appropriate technique. Nonetheless, in research contexts where classical measurement theory assumptions hold and the collection and analysis of quantitative data are necessary, it is advisable for researchers to avoid judgmental sampling and instead employ probability sampling techniques.

One potential limitation of our study on WBL was the absence of certain experts, including processors, packers, and transporters, who could have provided valuable insights. Unfortunately, their unwillingness to participate was mainly due to restrictive policies, particularly in private companies. However, this limitation was partially compensated for by the valuable information provided by other interviewees, particularly the CEO of the local agricultural cooperative, the technical inspector of Grain Company and Commercial Services (GCCS), and a high-ranking officer at the Ministry of Agriculture. These individuals possessed expertise and knowledge in areas where other experts did not participate in the survey. Therefore, the collected data can still provide relevant insights into loss and waste hotspots along WBL. However, it is important to note that the absence of some experts may still have resulted in overlooked information in certain segments. Future studies should aim to include a broader range of experts to gain a more comprehensive understanding of WBL and identify further loss and waste hotspots.

One drawback of this paper is that it did not provide any quantitative data. This was partly due to the sampling strategy used, which, as discussed above, does not permit the analysis and reporting of quantitative data in a representative and generalizable manner. Additionally, the lack of transparency in both private companies and public authorities was a significant hurdle. The study revealed that material flow records were well-documented and often submitted to the Ministry of Agriculture, GCCS, or the Union of Bakers, making them potentially obtainable. Nevertheless, despite our extensive efforts, our request to access quantitative material flow data to determine loss or waste was denied due to restrictive policies. To overcome such obstacles in future research, it is necessary to collaborate with stakeholders and policymakers to develop policies that promote transparency and access to data. This can be achieved through building partnerships between researchers, public authorities, and private companies to facilitate data sharing and establish transparent data reporting mechanisms. By doing so, researchers can gain access to relevant data to conduct comprehensive studies and inform evidence-based policies to address food waste and loss at different stages of the food supply chain.

Furthermore, it is essential to acknowledge that the data used in this study were collected in October 2018, and there have been significant global events, such as the COVID-19 pandemic and the Russia–Ukraine conflict, that may have impacted the wheat and bread supply chain since then. A study on the Italian artisan bread supply chain by Amicarelli et al. [139] revealed that the input costs for wheat farming increased by 62%, the milling process by 76%, and bread production by 265%, with an average input cost increase of 232% across all three stages during the Russia–Ukraine conflict. Similarly, prices and trades have been subject to fluctuations and inflation in Iran. Particularly, the wheat supply chain in Iran faced a major setback due to the Russia–Ukraine conflict, given that Iran imported nearly 20% of its wheat from Ukraine [140].

However, the structure of WBL, as presented in this study, is unlikely to be significantly affected, as the qualitative nature of this study makes it less prone to change over time. Therefore, the results can still be considered valid for gaining insights into WBL and identifying loss and waste hotspots in the target region. In some cases, qualitative data can be more resistant to change because it is often based on in-depth interviews, observations, and other forms of data collection that allow for a deeper exploration of a phenomenon [141]. This depth and richness of data can make it more durable and less susceptible to changes in the external environment [142].

Additionally, although the data were collected in 2018, the study’s findings are still relevant today as they highlight critical data gaps that have yet to be addressed. To the best of our knowledge, no study or official report has been published since the data collection to change the status of these knowledge gaps, apart from the references cited in this paper. Therefore, while we acknowledge the limitations of using the data from 2018, we believe that this study’s findings are still valuable and relevant to addressing the issue of wheat and bread loss and waste in Fars province, Iran, and beyond.

4. Conclusions

The present article provides a detailed cradle-to-grave overview of the WBL in Fars province. The study's findings revealed that farms, foodservice facilities, and households were the primary wheat loss and waste hotspots in the province. The interviewees also explained that records of the material flow exist throughout WBL at all stages except for households. Moreover, there is insufficient information regarding the on-farm loss of wheat. Therefore, gathering primary data is crucial to fill the knowledge gaps on on-farm loss and household waste.

Data availability at other stages of WBL has not been leveraged to report loss and waste, emphasizing the need for studies that compile these data for estimating wheat and bread loss and waste. However, accessing data possessed by private companies or public authorities remains a challenge, highlighting the pressing need for enhanced transparency. Access to data from various stages of WBL is imperative for researchers to accurately evaluate the extent of loss and waste and develop effective strategies to reduce it. Public authorities have a crucial role in promoting data sharing and transparency in the industry. By incentivizing private companies to disclose the material flow data, public authorities can encourage increased participation from private actors in reducing wheat and bread loss and waste.

Despite its specific focus, this study has implications in broader contexts for research and business in cereal production and FLW reduction. The study's outcome will be valuable not only to researchers studying FLW but also to those conducting LCA and circular economy studies on wheat and other cereals or similar food items in different geographical and socioeconomic contexts. The use of VSM in the present study resulted in a detailed and inclusive portrayal of WBL which can be useful in defining a clear and accurate scope in LCA and circular economy studies, minimizing the risk of overlooking essential lifecycle segments. Furthermore, the comprehensive description of the WBL presented in this study can serve as an educational tool for researchers and practitioners seeking to expand their knowledge of cereal production and supply chains.

In conclusion, accurate and up-to-date data inventory is essential for monitoring FLW throughout the food lifecycle and developing effective reduction plans and strategies. By collecting and analyzing data on the material flow at food production, processing, distribution, consumption, and disposal, stakeholders in the food industry can identify areas for improvement, set goals, track progress, and develop innovative solutions. Nonetheless, the stages of the food lifecycle where loss and waste can be attributed to multiple factors, rather than mainly material flow, require closer examination. Future research should focus on studying on-farm food loss, which depends on a complex set of biological, technological, chemical, and climate elements, and household food waste, which is affected by habitual, behavioral, and psychological factors. In addition to accurate quantification of FLW, a more comprehensive understanding of causes and affecting factors is crucial to paving the way to achieve goals for establishing a sustainable and responsible food production and consumption system.

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Chapter 3: Article 2

Title of the Article: Unraveling On-Farm Wheat Loss in Fars Province, Iran: A Qualitative Analysis and Exploration of Potential Solutions with Emphasis on Agricultural Cooperatives

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Abstract

Given wheat's global significance as a primary food crop, and its importance in providing essential nutrition to millions of people worldwide, reducing on-farm losses is crucial to promoting food security, sustainable agriculture, and economic stability. Wheat plays a critical role in food security in Iran, as it is a staple food consumed daily by a large proportion of the population, and is also a vital component of the country's food self-sufficiency policy. The present study aims to identify the causes and extent of on-farm wheat loss in Fars province, a major wheat-producing area in Iran. Nine experts were interviewed, using open-ended questions, in October 2018. The study revealed that a considerable amount of wheat is lost due to seed overuse, pest infestation, and improper harvesting. The paper discusses the underlying factors associated with these over-arching causes, and highlights their adverse environmental, economic, and societal impacts. The paper also explores potential approaches to take in addressing the issue, and suggests empowering agricultural cooperatives through changes in the government's engagement with wheat production. This study provides valuable insights for policymakers and stakeholders which are useful for developing effective strategies to reduce on-farm loss, particularly in countries where intensified farming is promoted. These strategies may include limiting the government's central control and, instead, empowering agricultural cooperatives, as well as adopting supportive approaches, such as improving farmers' access to proper machinery, and enhancing their sovereignty and freedom.

Keywords: food loss and waste; cereals; developing countries; harvest loss; seeding efficiency; cooperative farming.

1. Introduction

Apart from the inherent food loss resulting from natural causes, inefficient cultivation, harvesting, and handling practices contribute to on-farm food loss [1,2]. Cereals undergo significant loss and waste across the food supply chain. Following fruits and vegetables, cereals hold the second position globally, with an estimated 30% of their production lost and wasted [3]. Meanwhile, cereals are the largest contributors to the carbon footprint of food loss and waste, accounting for almost 35% of the total [3]. There is a lack of comprehensive data regarding the extent of on-farm cereal losses. Based on estimates by the Food and Agriculture Organization (FAO), the largest proportion of cereal losses—over 2 billion tonnes—occurs at the farm level [3]. In developed countries, primary production accounts for approximately 2% of cereals lost, while in developing countries, it is responsible for the higher proportion of 5–7% of cereal losses [2]. Efforts are underway to conduct additional studies on food loss quantities, to address data gaps, and reduce uncertainty. For example, the FAO has been conducting product-focused case studies to fill the data gaps, particularly in developing countries [4–8].

While the quantification of food loss is vital in monitoring progress in reducing waste, it does not offer a comprehensive understanding of the issue. Qualitative studies are also crucial to exploring the multifaceted nature of food loss and waste, identifying the underlying causes, and devising effective mitigation strategies [9]. Such insights can inform the development of more targeted policies and programs for reducing food loss and waste [10]. Several factors contribute to on-farm loss in the production of cereals, including pests and diseases [11,12], unfavorable climatic conditions, substandard agricultural practices, limited access to adequate storage and handling facilities, and financial constraints [1,13,14]. However, these factors may vary, depending on the circumstances, as a farm’s productivity is influenced by multiple aspects, such as the climate, location, soil characteristics, water availability, and plant variety [15]. Therefore, it is of the utmost importance to investigate the underlying causes of on-farm loss in the production of cereals in different geographical regions, to enable the development of context-specific loss-reduction policies.

Wheat is considered one of the foremost cereal crops in the world, primarily due to its affordability, which contributes to its extensive consumption and trade as a food commodity. It plays a crucial role in providing millions of individuals with the necessary calories and essential nutrients. Wheat is a rich source of fiber, protein, and other vital nutrients essential for sustaining optimal health [16]. Beyond their nutritional value, wheat and bread are deeply rooted in the cultural and social spheres of many societies, playing a pivotal role in their traditions and customs [17]. As of 2020, global wheat production exceeded 760.9 million tonnes, representing more than 8% of the total crop production worldwide, and positioning it as one of the four principal crops that, together, constitute half of the global primary crop production [18]. A report published by Fortune Business Insights [19] suggests that the global market for wheat flour will grow from USD 160.66 billion in 2021 to USD 210.77 billion by 2028.

For centuries, Iran has heavily relied on wheat as a staple food that provides sustenance to 80 million people, and plays a crucial role in shaping the country's economy, culture, and culinary heritage. Table 1 provides a comparative overview of the total wheat production in 2020, showcasing the top-ranking countries globally, with a specific emphasis on Iran's position. The data are sourced from the FAO's 2022 food and agriculture statistical yearbook [18], and include neighboring countries of Iran for additional regional context. Iran's wheat production in 2020 reached 15 million tonnes, placing the country 12th globally. This amount represented approximately 20% of Iran's total crop production, which amounted to 74.4 million tonnes [18]. Additionally, Iran imported 1,181,600 tonnes of wheat without any export in 2020 [18]. During the cultivation period in 2020 and 2021, an estimated 6.7 million hectares in Iran were utilized for wheat production, comprising approximately 43% of the total crop-production area, and nearly 57% of the area allocated for annual food-crop production [20].

Table 1. Comparative analysis of wheat production in 2020.

Rank	Country	Wheat Production in Thousand Tonnes
1	China	134,255
2	India	107,590
3	Russian Federation	85,896
4	USA	49,691
5	Canada	35,183
6	France	30,144
7	Pakistan	25,248
8	Ukraine	24,912
9	Germany	22,172
10	Türkiye *	20,500
11	Argentina	19,777
12	**Iran**	**15,000**
22	Iraq *	6238
25	Afghanistan *	5185
42	Turkmenistan *	1320
45	Azerbaijan *	1819
76	Armenia *	132

* Iran's neighboring countries with a land border; source: FAO [18].

International sanctions have significantly impacted Iran's economy over the last decade, leading to a reduction of nearly 50% in the country's crude oil exports from 2011 to 2015 [21].

The U.S.' "maximum pressure" policy further aggravated the situation, by impeding Iran's access to international financial services, leading to a reliance on overexploiting its natural resources to counteract the sanctions and attain self-sufficiency [22,23]. To achieve self-sufficiency in wheat production, the Iranian government has been implementing different measures, including the provision of heavy subsidies for plant protection products (PPPs) [24]. Although initially effective, the adoption of intensive agriculture, and the increased use of pesticides, have been proven to have significant long-term consequences, such as environmental degradation, soil depletion, and the emergence of pesticide-resistant pests, as well as adverse effects on human health [25]. Given this context, it is imperative for Iran to prioritize the optimization of wheat production efficiency, particularly through reducing on-farm losses. It is, therefore, essential to conduct comprehensive studies to examine the extent and causes of these losses.

The Fars province is a significant contributor to Iran's wheat and bread industry, owing to its favorable climate and fertile soil. Although Fars is the 11th-largest province in terms of wheat cultivation area, it holds the position of the second-largest wheat-producing province among Iran's 31 provinces [20]. Fars annually produces over 1.2 million tonnes of wheat, which constitutes more than 8% of the country's total wheat production [20]. However, as Ghaziani et al. [26] highlight in their study on loss and waste throughout the wheat lifecycle in Fars province, there is a major knowledge gap concerning the extent and causes of on-farm wheat loss. Given the importance of this province, conducting research to fill this knowledge gap can inform targeted interventions and policies to reduce such losses, promote sustainable wheat-production practices, and contribute to Iran's food security.

The Iranian government exerts significant control over the wheat market, which could have a negative impact on agricultural productivity. Feili et al. [24] argue that reducing government intervention could empower self-governance among farmers, and enhance wheat production. Agricultural cooperatives, with their bottom-up democratic structure, can foster cooperation among farmers, and improve productivity. Despite actively engaging in the wheat supply chain in Fars, agricultural cooperatives have yet to realize their full potential [26]. This indicates a need for diagnostic exploration, to identify areas for improvement.

This study aims to investigate the issue of on-farm wheat loss in Fars, focusing on understanding the underlying causes of this problem, and identifying potential solutions. By examining the role of cooperatives in addressing this issue, the study aims to provide valuable insights into the potential for cooperative models to promote sustainable farming practices. By doing so, this study seeks to make a significant contribution toward improving agricultural productivity. The findings can help policymakers, farmers, and cooperatives in adopting sustainable farming practices that enhance wheat production and minimize losses, thus fostering a more efficient and sustainable food system.

2. Material and Methods

2.1. Participants

Conducted in October 2018, the survey involved interviewing nine experts and practitioners who play an active role in wheat production in Fars. The selection of participants was based on judgmental sampling. Participation in the survey was voluntary, and interviewees were informed and assured of the confidentiality and anonymity of their data. The participants have been listed anonymously in Table 2, based on their role in the wheat supply chain. To maintain confidentiality, their assigned IDs from Table 2 will be used throughout the report. For example, the chief executive officer (CEO) of the local agricultural cooperative will be identified as Co-op CEO.

Table 2. List of participants according to their professional roles.

Participant's ID	Role
Seed producer	The owner of a plant breeding and seed production company
Farmer 1	A farmer with large-sized (over 70 ha) land
Farmer 2	A farmer with small-sized (10 ha) land
Farmer 3	A farmer with small-sized (10 ha) land
Farmer 4	A farmer with small-sized (20 ha) land
Farmer 5	A farmer with small-sized (20 ha) land
Co-op CEO	The chief executive officer (CEO) at a local agricultural cooperative and a farmer with a medium-sized (50 ha) land
GCCS inspector	The technical inspector of Grain Company and Commercial Services (GCCS) of Fars province
Agri. Mins. Officer	A high-ranking officer at the Ministry of Agriculture

2.2. Interviews

Expert interviews were conducted to gather qualitative data on the causes and reasons for on-farm wheat loss, as well as possible solutions to mitigate this issue. The data were collected through open-ended questions, allowing the experts to provide detailed and insightful responses. The interviews were conducted in person, and lasted between 30 and 90 min. The questions were designed to explore the participants' experiences and perspectives on wheat loss, including the factors that contribute to the problem, and potential solutions to address it. The interviews were recorded for later analysis, and notes were taken as an additional source of data. Following Guest et al.'s [27] guideline, the conduct of further interviews ceased once no new information was obtained from the most recent participants. The recommendations by Guest et al. [27] emphasize that sample size determination in non-probabilistic sampling strategies, such as the judgmental sampling employed in this study, relies on data saturation as the decisive factor.

2.3. Data analysis

MAXQDA software [28] was used to systematically code and analyze the interview transcripts, employing the qualitative open-ended survey data analysis approach explained by Fielding et al. [29]. The participants' statements during the interviews were regarded as a direct reflection of their comprehension of the questions. The first author transcribed the interviews, and translated them from Persian to English. Afterward, the participants' responses were structurally coded, and subjected to qualitative analysis.

3. Results and discussion

According to the participants' statements, considerable on-farm wheat loss occurs due to excessive seed use in planting, pest and weed infestation, and harvesting inefficiencies. In the following discourse, the underlying causes for the incidence of wheat loss on agricultural lands in Fars province will be elucidated. Figure 1 provides an abstract and simplified overview of the primary reasons and factors influencing on-farm wheat loss, based on the statements of the participants. Subsequently, a thorough and comprehensive analysis of the subject is presented, through the incorporation of direct quotations from the participants, and supporting evidence from the literature. Furthermore, comprehensive measures to mitigate such loss will be examined in depth. The final part of the study focuses on the role of cooperatives in Fars province, examining their impact on productivity and on-farm loss reduction.

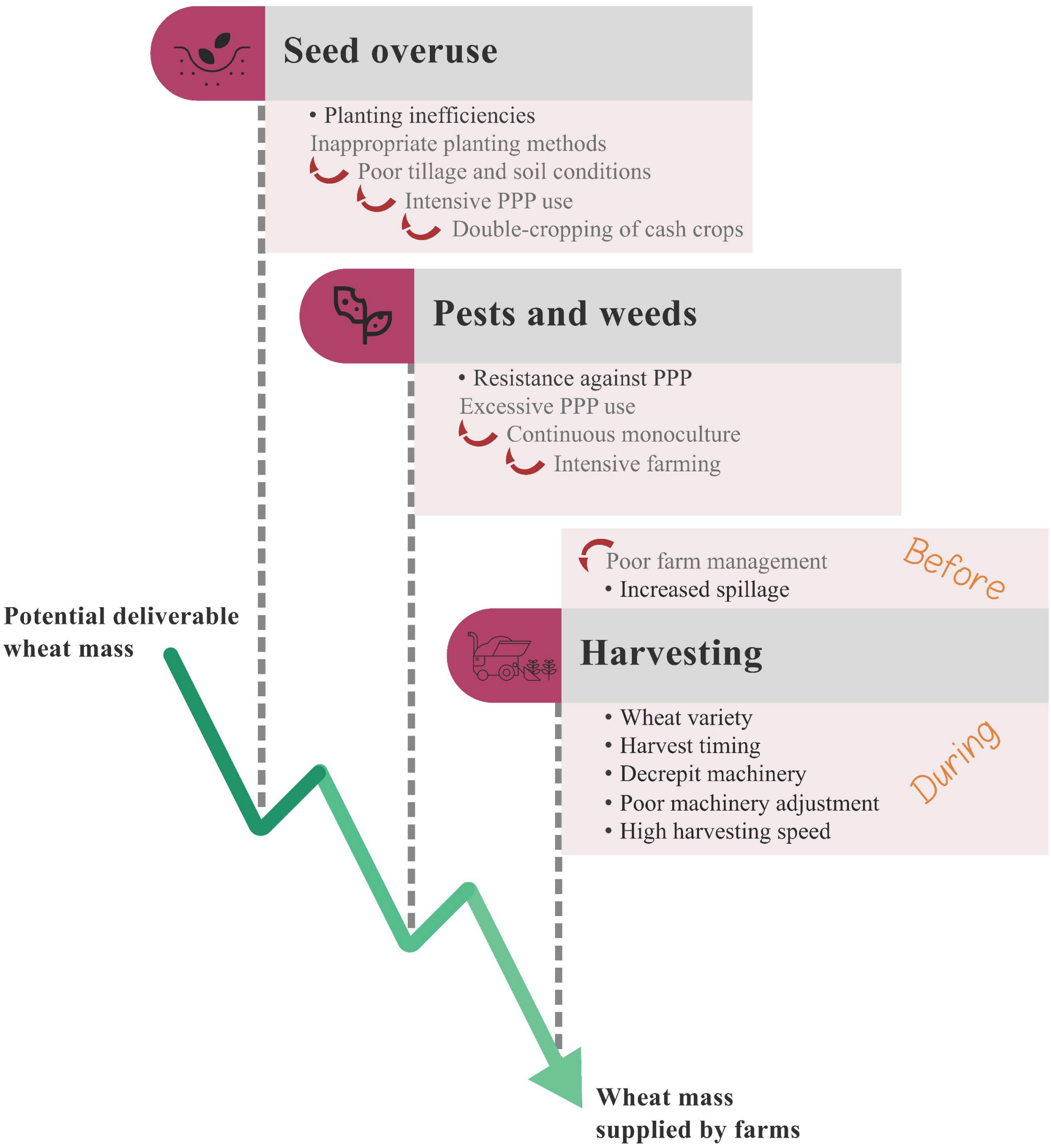

Figure 1. The underlying causes of on-farm wheat loss in Fars province. PPP = plant protection products.

3.1. Loss due to excessive seed use

Evidence suggests that farmers in the target region commonly overuse seeds, to ensure a desirable yield level, and avoid economic loss.

"A part of the wheat loss is due to excessive seed use." (Agri. Mins. Officer)

"Theoretically, only about 120-140 kg of seed is needed for wheat cultivation. But farmers have to sow 300 kg of seeds to succeed." (GCCS inspector)

"I sow more than 300 kg seeds per ha, sometimes even more than 400 kg" (Farmer 1)

"I plant 320-350 kg seeds per ha." (Farmer 5)

The Jihad Agriculture Fars Organization advises farmers in the region to sow170 to 180 kg of seed per ha in usual cases, and up to 225 kg per ha in cases of delayed cultivation [30,31]. For colder regions, a slightly increased amount of seed might need to be planted [31]. Generally, 180 kg of seed per ha is used in agricultural experiments on wheat in Iran [32,33]. A study in the Dezful region, a semi-arid area in Khuzestan province in the southwest of Iran, indicated that a seed density higher than 100 kg per ha negatively affects the wheat yield [34]. However, despite the recommendations, farmers often arbitrarily determine their seeding density, and rely on chance, to some extent.

"I planted about 240 kg per ha. I did not have a specific reason for choosing this number. I would say 240 kg was enough; one would argue 300 or more needs to be planted based on another reasoning. There is an old saying: the lands in this region perform well regardless of which and how much seed you plant." (Farmer 3)

The excessive use of seed in Fars province means that a considerable amount of seed planted with low efficiency is lost. This loss could be channeled toward consumers, or used to produce more wheat, potentially increasing food availability. In other words, the overuse of seed leads to a decreased edible food mass, which, according to the FAO's 2011 definition [2], is classified as food loss. These results are consistent with the findings of Horton et al. [35]. According to Horton et al. [35], food loss and waste can originate at the early stages of the food chain, such as seed use, appropriate plant varieties, and agrotechnology, resulting in a significant gap between the potential and realized yields, which often goes unnoticed by farmers. Avoiding such losses has significant implications in terms of food security and access, as it helps ensure that more individuals have access to a stable and sufficient food supply.

This study cannot provide an accurate representation of the frequency and amount of excessive seed use. Nonetheless, the results revealed that practical incentives and logical justifications could convince a large number of farmers to sow seed above the recommended amount. In general, many farmers take a conservative approach, to avoid economic loss.

"It is very difficult to introduce a new thing to the farmers. They would certainly not accept implementing something new unless all others try that and assure them that it would work." (Seed producer)

"I am known as a pioneer farmer. Yet, I do not plant less than 350 kg seeds per ha, regardless of how much they [the AREEO experts] insist. . .. I say if we spend more money per ha, my mind would be at ease that we would harvest five to six tonnes per ha. We may harvest the same amount if we seed 100 kg per ha. But we would be worried all the time as to whether it works or not." (Farmer 1)

Previous studies showed that higher seeding densities do not necessarily result in a higher yield, and the optimal seeding density differs depending on the climatic and geographical conditions [36,37]. Nevertheless, optimal densities are typically determined in controlled experimental settings or, at least, under ideal farm management conditions.

"We had around 200 kg of seeds of a new variety. We were asked to test these seeds for wheat cultivation in Fars province. The requirement was to use no more than 25 kg of seeds per ha. We planted 25 kg seeds per ha using an experimental seeder. How much do you think the yield was? More than seven tonnes per ha. However, the cultivation was highly controlled in terms of pests and weeds." (Seed producer)

Some farmers might have tried to follow the recommendations, and failed.

"I heard a rumor that someone sowed 60 kg seeds per ha in [name of a region]. After that, I planted less than 300 kg per ha. The AREEO experts evaluated the tillering in my field as moderate. This means my wheat was grown less than my typical performance. Imagine how bad the performance could have been if I had sowed only 100 kg seeds per ha." (Farmer 1)

The participants' statements indicate that the failure to plant the recommended optimal seed density is a result of the implementation of improper seeding methods.

Farmers in the Fars region primarily rely on broadcast seeding, mainly with a centrifugal spreader, followed by a run with a disk tiller, which is chosen for time efficiency.

"In this region, maybe only up to 30% of farmers use drill seeders, while more than 60% use centrifugal broadcast machines and a small minority who have small farms do the traditional manual seed spreading." (Co-op CEO)

"We tillage the land, plant the seed either with a centrifugal broadcast planting machine (normally around 300–350 kg per ha) or manually (around 320 kg per ha) and run a disk tiller." (Farmer 4)

However, this choice comes at a cost, as broadcast seeding is less efficient than the drill method [38,39].

“The seeds will grow with minimum precipitation when you use a proper planting machinery.” (Farmer 3)

Despite this, many farmers do not opt for drill seeders, due to the added cost and time required for their use. Additionally, drill seeders are not well-suited for lands with poor tillage, which is common in the region.

“An issue in this region is that most of the lands are also used for rice cultivation, which makes the land unsuitable for a drill seeder. The land will have many soil clumps after rice cultivation which cannot be broken entirely by tillage. Therefore, a drill seeder cannot operate well on such lands.” (Co-op CEO)

The result is a situation in which farmers are forced to choose between efficiency and practicality, with the latter often taking precedence. This is why farmers in Fars province prefer to use broadcast seeders and run a disk tiller, to save time and reduce costs.

“It’s a matter of work speed. We can get the job done in two hours using a broadcast seeding machine.” (Seed producer)

“Some farmers use drill seeding machines. Others do not believe that using such machinery is economically sound. A drill seeder works 5 ha per day, 7 ha at best. Farmers who cultivate two crops in one season want to plant 30 ha of land in two days. Or rain is forecasted, and they need to plant their seeds as soon as possible. So, they use a broadcast seeder and run a disk tiller afterward.” (Farmer 2)

As a consequence, parts of the wheat seeds are not planted at the optimal depth. The depth at which wheat seeds are planted significantly impacts their ability to germinate and thrive [40].

“The wheat seed in temperate areas such as Shiraz [the capital of Fars province] and soundings should be embedded in a depth of 2 to 3 cm. In colder areas, it is said that they grow better when seeded 7 to 8 cm deep to avoid frost. When wheat sprouts, its coleoptile has to reach the surface. Once the coleoptile reaches the surface, the plant starts its growth. If you imbed the seed 15 cm deep, the coleoptile will dry up after growing 4 to 5 cm.” (Seed producer)

“When I dug the soil a bit, I could see the seeds sprouted but did not grow enough to come out of the soil and were dried up underneath the surface.” (Farmer 3)

Therefore, farmers tend to overuse seeds, to ensure that a large enough number of seeds turn to yielding crops.

“Parts of the seeds remain on the land surface, and parts go too deep and cannot grow. That’s why even knowledgeable farmers fear planting a low amount of seeds per ha.” (Seed producer)

“The disk tiller is strong. It places about a third of the seeds too deep. The other third stays on the surface and will be eaten by insects and animals. Only one-third will be planted in the optimal depth. This means out of 400 kg seeds, only 130 kg is optimally planted.” (Farmer 2)

While the lack of appropriate planting methods leads to excessive seed use, it appears that the primary factor is farmers’ inability to properly till their fields before seeding.

“A huge part of seed loss is due to improper tillage and soil conditions.” (GCCS inspector)

“The first reason [for excessive seed use] is the inability in optimal land preparation, mainly due to the unavailability of proper tillage equipment.” (Farmer 1)

There is ample evidence suggesting that improper tillage before planting wheat negatively impacts the yield [33,36,37,41–43]. Poor soil conditions impede proper tillage practices in the region.

“Those who seed 100 kg per ha prepare the farm properly to embed the seed in a certain depth so all the 100 kg can grow…. Whatever I do, my land does not reach the optimal condition for growing 100 kg per ha. I run the rototiller once and the disk tiller three times, and still, the sowing is highly inefficient.” (Farmer 1)

Double-cropping wheat and maize or wheat and rice is a predominant farming practice in Fars province. Double-cropping is the practice of growing two crops in a single growing season on the same plot of land [44]. Farmers may sometimes include vegetable farming in their planting schedule, too.

“The common crop rotation in this region is usually maize and wheat. In the regions where more water is accessible, farmers cultivate rice too.” (GCCS inspector)

“Crop rotation in this region is commonly rice and wheat or maize and wheat. Some farmers would cultivate tomatoes every three to four years too.” (Co-op CEO)

Based on the survey outcome, wheat farms in Fars province mostly do not lie fallow at all. These farms undergo wheat cultivation from the beginning of fall until the end of spring, and maize or rice is cultivated over the whole summer.

“Farmers cultivate maize right away after harvesting wheat. For example, they cultivate a maize variety with a growth period of about only three months.” (Farmer 1)

“We normally cultivate rice after wheat.” (Farmer 4)

“Depending on when wheat is harvested, farmers start transplanting rice seedlings between June and July and harvest rice from mid-September until mid-October.” (Co-op CEO)

Farmers are driven by economic incentives to continuously cultivate cash crops on their land, without taking any fallow period. Moreover, based on the participants’ statements, farmers owned larger farms in the past, allowing them to leave parts of the farm to fallow periodically.

However, recently, large farms have been divided and shared among more farmers who are the children of previous owners in many cases. This division of lands has left farmers with limited choices regarding crop rotation and fallow practices, unless they bear short-term economic losses.

"Another issue is the farm size. The farms are not large enough to be divided into different parts for cultivation and fallow. You see cases that five siblings inherited 10 ha, which they divided into five two-ha fields. They fail to work together, and there is not enough space to leave fallow. . . As long as the farmers have enough water, they don't leave their farms fallow." (Co-op CEO)

"The lands are divided among multiple farmers. Each person is trying to make maximum profit, so farming is more intensified. Farmers look for varieties with short growth periods. The new varieties need one or two irrigations less than the old ones, although their yield is slightly less. But it is economically justifiable because of timing." (Farmer 1)

Although double-cropping can have a number of positive impacts on soil in the short-term [45], its long-term implementation is considered to have detrimental impacts on soil [46]. The constant cultivation and disturbance of soil can lead to a loss of organic matter, and an increase in soil erosion [47]. Additionally, the repeated planting and harvesting of crops can lead to the depletion of essential nutrients in the soil, resulting in a decreased soil fertility and crop yield over time [48]. Furthermore, continuous grain-based double-cropping can also increase the risk of soil-borne diseases and pests, as well as promoting the growth of weeds, which can further degrade soil health [49].

Cultivating a high-demand crop such as maize after wheat, in particular, can lead to reduced soil fertility [49]. Maize production, like other forms of intensive agriculture, can have a number of adverse effects on soil health. One of the main concerns is the depletion of soil nutrients, particularly carbon, nitrogen, available phosphorus, exchangeable potassium, and exchangeable calcium, due to maize plants' high demand for these nutrients [50]. Therefore, farmers may need to implement intensive fertilization after maize cultivation, to achieve a high wheat productivity.

"To harvest 10 tonnes per ha, farmers need to irrigate several times (up to seven times) and use a lot of chemical fertilizers and pesticides." (Farmer 4)

The heavy use of pesticides and herbicides in maize production can lead to a decrease in the soil microbial activity, and a reduction in the populations of beneficial microbiomes and invertebrates [51]. This can decrease the overall health and productivity of the soil [52]. Additionally, the tillage practices associated with maize cultivation can lead to a decrease in soil organic matter, which can negatively impact the soil structure, water-holding capacity, and overall fertility [53].

"In the past, one run of a disk tiller per year was enough. Now we need to run a heavy disk tiller to break the soil lumps, which are rigid due to the overuse of fertilizers. The soil has lost all of its organic matter. That's why the farmer has to run the disk tiller three times after plowing. Then the farmer has to run a leveler." (Farmer 2)

Rice production has also been identified as having multiple adverse effects on soil.

"If we cultivate rice before wheat, we need more wheat seeds (more than 350 kg per ha). Because rice cultivation takes up many nutrients in the soil and also leaves too humid of land behind. Therefore, the tillage cannot be performed properly, and more seeds are needed." (Farmer 4)

Sowing wheat immediately after rice cultivation decreases the chance of seeding success, due to the highly moist soil conditions [54]. This is essentially due to the irrigation practices implemented in rice cultivation.

"The fields in this region [the Dorodzan area in the north of Fars province] are used for rice production. Almost all farmers use basin irrigation for wheat cultivation." (Co-op CEO)

One of the main concerns regarding the long-term cultivation of rice on one piece of land is the depletion of soil nutrients, particularly nitrogen and potassium [55]. More importantly, the long-term sequential cropping of wheat and rice removes enormous amounts of nitrogen, phosphorus, and potassium from the soil [56]. This is due to the heavy use of fertilizers, and the constant flooding of rice fields, which can wash away essential nutrients [55].

"Farmers use Urea fertilizer excessively. Urea fertilizer makes the land rigid. Overuse of Urea fertilizer is one of the main reasons that we cannot tillage the lands optimally." (Farmer 1)

The constant flooding of rice fields can also lead to the buildup of toxic levels of methane and other greenhouse gases, contributing to climate change [57]. Additionally, rice cultivation can lead to an increase in soil acidity [55], making it difficult for other crops to grow [58]. Furthermore, the use of pesticides and herbicides in rice production can have a negative impact on soil health, reducing the populations of beneficial microorganisms and invertebrates [59].

The issues linked to maize and rice cultivation and their sequential cultivation after wheat can, ultimately, lead to a reduced soil fertility and decreased crop yields, thereby affecting the efficiency of wheat seeding. Generally, soil quality is vital to ensuring the productivity of agriculture, and preserving the environment and biodiversity [60]. Moreover, the quality of food products relies on the quality of the soil [61]. For instance, continuous grain-based double-cropping requires intensified fertilizer and PPP use [62], which can lead to food products endangering public health [63]. In general, the lack of diversified crop rotations forces farmers to rely on extensive fertilization to maintain a high productivity. The application of nitrogen (N) fertilizers to annual row crops may result in nitrate leaching into the groundwater, posing a potential threat to human health [64,65].

Soil preservation through the implementation of sustainable farming techniques can lead to the achievement of a higher seeding efficiency [66]. The proper utilization of seeds can play a crucial role in increasing food production, and improving food security. It is important for farmers and policymakers to be aware of these issues, and implement effective measures, to optimize seed utilization and maximize food production. Clearly, farmers in this region need to reconsider their cultivation strategies. Diversified crop rotation could be an alternative for mitigating the adverse effects of the continuous double-cropping of cash crops [62]. Diversifying crops would not only improve the yield, but could also promote soil health, by maintaining balance in the soil biodiversity, increasing the efficiency of nutrient utilization, improving the soil structure, and reducing the presence of harmful pathogens in the soil [67,68]. Nonetheless, choosing the crop species and their sequences requires special attention to their pest–host specificity and redundancy, to avoid the emergence of soil-borne diseases [69–71]. Generally, a diversified crop rotation benefits the environment, especially through the improvement of the diversity in the soil fauna [72,73].

In the case of wheat production, cultivating grain legumes or various chickpea cultivars before wheat can increase productivity, by fixating biological nitrogen and increasing its availability, and promoting the functional soil fauna and microorganisms [74,75]. Moreover, longer rotation periods can be beneficial to soil health, hence increasing wheat cultivation productivity. A comparative study on different rotation periods in wheat cultivation revealed an increased soil health during the wheat phase of the 5-year rotation compared to the 3-year one, due to a higher microbial biomass [76]. Another study within the same research project showed that the wheat yield amounts were 23–82% higher under various rotation periods, compared to the continuous cultivation of wheat [77]. Overall, the current trend of wheat cultivation in Fars province is not only harming the environment, but could also lead to a reduced seeding efficiency and overall productivity, while increasing production costs due to the need for intensive fertilization. Therefore, the adoption of diversified crop rotation and sustainable farming techniques is crucial in promoting soil health, increasing productivity, improving food security, and preserving the environment and biodiversity.

3.2. Loss due to weeds and pests

Plant pests and weeds can have significant negative effects on food security, impacting crop production, increasing costs, and potentially threatening human and environmental health on a global scale. Pests and weeds are contributing factors to the on-farm loss of wheat.

“A part of the loss is due to insect infestation.” (GCCS inspector)

“Pests are also a major cause for losing parts or entire wheat crops.” (Farmer 3)

Globally, crop productivity is reduced by 20–40% due to the yield losses caused by pathogens, animals, and weeds [78–80]. The incidence of pest-induced wheat losses varies geographically, with rates of about 14% observed in Europe, and rates above 35% reported in African and Asian countries [81]. Pests and weeds can cause significant damage to crops, resulting in a loss of yield, and reduced quality of the wheat [78,82]. Farmers are facing increasing challenges in producing wheat, due to the emergence of new species of pests and weeds.

"We are facing pests and weeds that did not exist, let's say, 30 years ago. I have been cultivating wheat for more than 40 years. The production costs for wheat cultivation were around 22% of the gross income, although the yield was lower than now. The costs are now more than 50% of the wheat cultivation. The costs of purchasing pesticides are very considerable." (Farmer 1)

The harm caused by the long-term lack of diversified crop rotation, which was previously explained, is once again evident in this context. The continual cultivation of similar crops can result in the emergence and establishment of host-specific pests [83]. Moreover, continuous monoculture requires increased use of PPPs [84], endangering the environment, biodiversity, and human health [25]. The problem is further exacerbated by the fact that these new pests and weeds are resistant to traditional PPPs.

"We need to use a new pesticide every year because the pests develop resistance to the old ones." (Farmer 1)

Pests and weeds develop resistance against PPPs as a result of evolutionary pressures, including repeated exposure to the same or similar active ingredients, and the selection of individuals with genetic mutations that confer resistance [85,86]. Moreover, the affordable PPPs that are currently available are not as effective in controlling these new species.

"Not all farmers afford to purchase effective pesticides. They need to buy Indian pesticides, which have to be applied three or four times to eliminate the pests." (Farmer 2)

As a result, farmers struggle to protect their wheat crops from pests and weeds, resulting in significant losses in yield. Moreover, the harmful effects of plant diseases extend beyond reducing yields, and can also negatively impact the quality and safety of food, as well as the economy [87]. This highlights the need for alternative pest and weed management strategies that are sustainable, environmentally friendly, and economically viable for farmers. Resistant weeds and pests are a significant challenge in modern agriculture. To effectively manage these issues, farmers should employ a combination of control methods, including rotational cropping [88,89], biological control [90,91], and integrated pest management [92,93]. Crop rotation involves growing different crops in a field during different seasons, which can help to reduce the buildup of pests and weeds [83]. For example, planting wheat after mung beans or a fallow period could potentially decrease growth [88,94]. Biological pest control involves using natural organisms or their derived products to control pests, rather than synthesized chemical PPPs [95]. Integrated pest management is an approach that combines multiple control methods, including cultural, biological, and chemical control, to manage pests and weeds effectively and sustainably [96]. Most importantly, farmers should also be mindful of not overusing synthetic chemical PPPs, to avoid the evolution of resistance in pests and weeds [85,86]. Overall, emphasizing the need for diversified and sustainable farming techniques is essential, much like addressing the loss resulting from seed overuse that was discussed earlier.

3.3. Loss due to harvesting

Another on-farm wheat-loss hotspot is before and during harvesting, with inefficiencies in the operation of combine harvesters being the primary cause in Fars province.

“Wheat is lost on a farm before or during harvest.” (GCCS inspector)

“The loss also occurs right before the plant is ready for harvesting.” (Farmer 3)

“The majority of loss occurs during harvesting on the farm.” (Co-op CEO)

“Wheat is harvested [in Fars] mainly using a combine harvester, which is a major point of loss.” (Farmer 1)

The loss of wheat before harvesting can result from several factors, including natural causes, such as bird predation or wind-blown spillage, and poor farm-management practices, such as inadequate irrigation or improper land preparation.

“Wheat loss before harvest is mainly due to wind or birds.” (GCCS inspector)

Natural causes typically account for a small proportion of the total harvest loss, except in catastrophic events [97]. However, poor farm-management practices can contribute more to wheat loss shortly before harvesting.

“If plants do not receive enough water at a critical time, about one month before harvesting, the wind will dry out the wheat head, which would cause loss. Leveling the land properly before cultivation would prevent this loss. If the land is uneven, the plants that are placed higher than others do not receive enough water and would dry out.” (Farmer 3)

Pre-harvest loss, whether due to the gain’s low moisture content or pests, can be prevented through prudent management practices, such as timely irrigation, adequate fertilization, pest control, and proper tillage and land preparation [98,99]. The level of preharvest loss can also vary depending on the chosen wheat variety, with different varieties having different levels of susceptibility.

“The pre-harvest loss is sometimes higher for some wheat varieties compared to the others.” (GCCS inspector)

Certain varieties can demonstrate favorable traits, such as disease or pest resistance, or low lodging or shedding, making them more renitent to pre-harvest loss [100]. Choosing such varieties can contribute to loss reduction [101]. However, although the attempts to reduce pre-harvest loss are undoubtedly helpful, the loss during harvesting is more detrimental, and requires extra attention.

Based on the participant responses, wheat is lost during harvest due to the following factors.

1. Wheat variety: different varieties of wheat can impact loss during harvest.
2. Harvest timing: harvesting too late can increase shattering.
3. Decrepit and misaligned machinery: outdated or poorly maintained machinery can result in a higher wheat loss.
4. Incorrect adjustment of the machinery: improper settings in the combine harvester can cause the loss of wheat.
5. Running the combine harvester too fast: operating the combine harvester at a high speed can result in a further loss of wheat.

The harvest loss level highly depends on the wheat variety.

“Some varieties have a higher loss during harvest. So, part of the harvest loss depends on the wheat variety.” (Seed producer)

Different wheat varieties have varying physical characteristics, which can affect their susceptibility to harvest loss. Choosing wheat varieties that possess traits that are favorable for combine harvesting can reduce the loss. These traits may include kernel attachment, stalk strength beneath the ear, and how the leaves and stem break in the threshing unit [100].

Another major factor influencing the harvest loss in wheat is the timing of harvesting.

“Reasons, such as late harvesting, can also cause loss.” (Co-op CEO)

The harvest timing must be carefully considered, as it can greatly impact the outcome. The delayed harvesting of cereals increases shattering, as the crops become excessively dry [102,103]. On the other hand, if the harvest is performed too early, the wheat may not have reached its full potential, resulting in a lower yield and decreased quality [104]. Moreover, wheat grains harvested prematurely have a high moisture content, which leads to a higher chance of decay and a low storability [105]. One of the challenges farmers face in properly scheduling the harvesting time is the unavailability of combine harvesters.

“The demand for combine harvesters is too high during the harvest period and it is difficult to find one at the best time for harvesting my crops.” (Seed producer)

Not all farmers can afford to own harvesting machinery. Most of the combine harvesters in Fars are owned by a certain number of individuals, and the number of harvesters available is not enough to simultaneously meet the high demand during the harvesting season. This brings up the next issue: the limited availability of efficient and modern combine harvesters.

Loss during combine harvester operation is unavoidable to some extent. However, misaligned machinery can lead to uneven crop cutting, causing some wheat to be left behind, while other areas are cut too closely, resulting in a lower yield. A high wheat loss may occur even when advanced combine harvesters are used, if they are not properly adjusted [97].

"New machines have a lower loss indeed, but only when they are well-tuned." (Seed producer)

"Another reason for loss during harvesting is an incorrect adjustment or technical issues of a combine harvester, which is the most significant reason." (Farmer 3)

Harvest loss reduction can be accomplished efficiently when farmers and combine operators have a clear understanding of how the machine works and how to adjust it [106]. Chen et al. [98] provided a detailed demonstration of the function of a typical combine harvester, which can be summarized as follows: a combine harvester cuts and gathers grains at the header unit, then threshes and separates them, removes impurities through cleaning, and transports clean grains to a storage tank. More than 60% of the machine-related loss during the harvesting of cereals occurs in the header unit [97,107]. Therefore, the maintenance and adjustment of the header unit require extra attention, to reduce the harvest loss. Future advances in real-time loss-monitoring technologies can improve the operation of combine harvesters [98]. Nonetheless, even advanced machinery cannot perform to its full potential unless it is driven at the correct speed [97].

The survey revealed that a considerable amount of wheat is lost because the machine operators drive the combine harvesters too fast.

"When a combine harvester operator runs the machine too fast on the land, the loss will be higher. The operator tends to finish the job as soon as possible, particularly when paid per hectare." (Seed producer)

"[Harvest loss happens] mainly due to harvesting too quickly. Especially the new combine harvesters have air conditioner and the operator is sitting in a cabin and does not care how much is lost." (Farmer 5)

There is evidence to suggest that the grain loss during harvesting increases in direct correlation with the speed at which the combine operates [108,109]. However, the harvesting loss depends not only on the forward speed, but also on the combination of the forward speed with the speed of other units, such as the reel and the threshing unit. The results of an experimental study on wheat in Sudan conducted by Abdalla et al. [110] indicate that the optimal combination for minimizing the wheat-harvesting loss was a forward speed of 4 km/h and a reel speed of 25 rpm. Another study by Lashgari et al. [111] in Iran revealed that the most effective combination of the forward speed and the cylinder rotation speed for minimizing the wheat harvesting loss and preserving the grain quality, e.g., breakage and germination, was a forward speed of 1.8 km/h and a cylinder rotation speed of 800 rpm. Considering the complexity of harvesting machinery, the need for educating the operators cannot be stressed enough.

“Combine harvesters are often operated incorrectly, resulting in a high amount of loss that is due to operators’ lack of skill or experience.” (GCCS inspector)

To tackle this issue, in addition to enhancing technical education, it is necessary to offer better wages for combine operator jobs.

“Another reason for harvesting loss is the lack of skilled and trained combine operators. Skilled operators demand high wages because it is a difficult job.” (Co-op CEO)

Low wages can lead to job dissatisfaction and a shortage of skilled labor [112]. Additionally, the operators may be more likely to drive combine harvesters too fast if their payment structure incentivizes speed over efficiency.

“The combine operators mostly get paid either per hour or per hectare…. [grain loss] is not important for them at all. They just want to get the job done as soon as possible.” (Co-op CEO)

Some may argue that by reinforcing supervision during harvesting, farmers can improve the combine operators’ performance, and optimize their yield.

“The more the farmers supervise the harvest, the more they can prevent loss.” (Seed producer)

However, due to limited resources and time constraints, many farmers are unable to provide constant supervision. This is particularly challenging for small-holder farmers, who may lack the financial and human resources necessary for effective monitoring.

“Harvesting takes more time on a large farm. A large-scale farmer can supervise the process and instruct the combine operator to make necessary adjustments or change the speed if they observe that the yield is insufficient or if the first batch delivered to the purchasing center is evaluated as poor [in terms of impurity and broken grains]. But harvesting on a small farm may be completed in one run and there is no room for correction. . .. I own a large farm. I can afford to hire a supervisor. But farmers who own smaller farms, such as those with only 10 or 15 hectares, may not have the necessary knowledge to supervise harvesting or may not be able to afford a supervisor. It takes four to five days to harvest my farm. Their [small-holder farmer] entire farm will be harvested quickly. They notice that the loss is high when their entire yield has already been harvested, and the damage is done.” (Farmer 1)

The interviews revealed that even alternative payment arrangements, such as working on commission, may not deter combine operators from causing losses.

“In some regions, combine operators work for a percentage of the income. Even those who work on commission don’t care much about loss.” (Co-op CEO)

“Sometimes, the combine owner does not charge the farmer for harvesting. Instead, the combine owner collects the straws to sell as forage. In those cases, the combine operator may adjust the combine header lower to collect more biomass and make more profit, which leads to more wheat loss and impurity content in the yield.” (Farmer 4)

Generally, the issue still remains that some combine operators prioritize their own profits over minimizing loss and maintaining crop quality. To address this issue, one possible solution is to standardize the payment structure for machine operators. For instance, in addition to the area- or time-based payments, operators could be paid performance pays based on the harvest loss and the impurity level. However, major challenges would be monitoring the loss during harvesting, and tracing the harvested batch back to the combine operator, emphasizing the need for the digitalization of food supply chains. The effective monitoring of harvest loss is now a feasible approach, thanks to real-time sensor data [113]. Nevertheless, rational decision-making for investing in such advanced technologies requires thorough cost–benefit analyses [114]. Moreover, technologies such as blockchain or the internet of things (IoT) are powerful tools that not only ensure the traceability of the food items and actors involved throughout the supply chain [115], but also safeguard the transparency of monetary transactions, leading to decreased tax fraud and corruption [116]. Nevertheless, limiting factors, especially in developing countries, continue to be the lack of proper technological infrastructure or, in some cases, the intentional hindrance of internet access by authoritarian governments. [117].

An increased wheat loss also occurs due to decrepit and misaligned harvesting machinery.

“Unfortunately, dilapidated harvesting machinery causes enormous loss. For example, 60–70% of our harvesting machines are 50–60 years old.” (Co-op CEO)

The use of old and outdated combine harvesters may result in an increased grain loss, emphasizing the importance of investing in advanced harvesting machines equipped with the latest technologies to reduce harvest losses [118]. Outdated harvesting machines are responsible for a significant portion of wheat loss, and need to be replaced by more recent machines with advanced technologies [98]. Nonetheless, harvest loss is more commonly attributed to technical maintenance, rather than to the machine’s age. [97]. When farm machinery is not maintained properly, it may not function as intended, resulting in lost or damaged crops. Technical maintenance plays a crucial role in maximizing the harvesting efficiency. Poorly maintained equipment may be more prone to breakdowns, causing delays and loss of time during the harvesting process [97]. In Fars province, those who rent out their combine harvesters to farmers may neglect the timely maintenance of their machines, due to short-term economic incentives.

“Some owners of combine harvesters would rather keep their machines running all the time to maximize their profit and would skip the necessary maintenance. As a result, a considerable amount of wheat is lost due to technical problems with harvesting machinery.” (Farmer 3)

The greed of machine owners causes farmers to suffer economic losses due to poor harvesting operations, leading to a level of high grain impurity and loss. Besides the negative effect on agricultural productivity and farmers’ income, prioritizing short-term profit over maintenance can cause the machinery owners long-term economic loss. The lack of proper maintenance of farm machinery can lead to equipment failure, which may result in more expenses, due to the need for repairs or replacement [119], and early asset depreciation [120]. Moreover, the correct maintenance can reduce the costs associated with fuel consumption [121]. The maintenance costs are minimal compared to other costs associated with combine harvesters [122], and the potential losses resulting from poor maintenance practices [120]. Hence, investing in timely maintenance can mitigate these losses, enhance the overall efficiency of the harvesting process and, ultimately, outweigh the costs to the equipment owner in the long run.

Implementing technical maintenance regulations and regular mandatory inspections is crucial to maximizing agricultural productivity, and minimizing harvest losses [123]. Such measures may involve an initial investment, but this investment can help to prevent economic losses, leading to long-term cost savings, and an increased probability for the machinery owners. Additionally, mandatory technical inspections can mitigate the environmental impacts associated with the operation of poorly maintained farming machinery [124]. However, obligatory technical maintenance may impose additional costs on farmers, especially small-holder farmers.

Small-holder farmers may struggle to afford the cost of using advanced, well-maintained combine harvesters. Furthermore, the shortage of these machines during the harvesting season, previously mentioned as a factor hindering proper harvest timing, exacerbates the challenge farmers face in accessing harvesting machinery. This highlights the need for supportive policies, to facilitate collective action among small-holder farmers who might not have the resources to invest in expensive equipment.

“Most farmers [in Fars province] are small-holder farmers and don’t have a good financial situation.” (Seed producer)

Cooperative models, among other things, have great potential as a means to improve access to these critical resources. The following subsection delves into the role of cooperatives in mitigating on-farm wheat loss in the Fars region, including losses caused by factors beyond the harvest, such as pests and the excessive use of seed.

3.4. Reliability of the Results

The qualitative nature of the obtained data facilitated a comprehensive and detailed analysis of on-farm loss in the target region. Qualitative data derived from information-rich experts are considered a powerful tool in developing valid and reliable surveys [125,126] that enable an in-depth exploration of the causes and effects of a phenomenon [127]. By adhering to the principle of data saturation, the present study achieved a balance between gaining valid and reliable information, and maintaining survey efficiency. Data saturation in qualitative studies occurs when no new insights or information are obtained from additional data collection or analysis, indicating a comprehensive understanding of the research topic [128,129]. According to Guest et al. [27], data saturation in qualitative surveys can be reached within the first six interviews for meta-themes, while more detailed information may achieve saturation within the first twelve interviews. Given the similarities in wheat production, and low variation in farming techniques in the target region, it was reasonable to reach data saturation within the first nine interviews in this study. However, it is important to note that while the results presented in this study provide valid insights into the causes and effects of on-farm wheat loss, the quantitative information serves only to provide context, and indicate the overall magnitude of the issue, and not to provide the exact level of on-farm loss, due to the small sample size. Therefore, further quantitative studies with sample sizes adequate for quantitative analysis are necessary to accurately determine the level of on-farm wheat loss, and its correlation with agronomic measures, farm machinery settings, and various farming techniques.

3.5. The role of agricultural cooperatives in reducing on-farm loss

As discussed before, promoting ecologically friendly diversified rotational cropping in Fars province is vital to tackle the loss caused by seed overuse and pests. Cooperatives can play a pivotal role in this endeavor, by improving agricultural productivity, reducing on-farm food loss, and fostering a more sustainable food production and distribution system [130]. Cooperatives offer a significant advantage, in enabling participatory cooperation among farmers, which can promote sustainable farming practices [131]. Through collaboration, farmers can enhance their acceptance of these practices, leading to a more effective implementation of ecologically friendly cropping systems [131]. Moreover, cooperative efforts can result in savings on farming equipment and labor, as well as an improved knowledge and ability in using crop rotation and intercropping, further enhancing the sustainability of farming practices [131]. In addition, cooperatives can play a crucial role in helping farmers plan their crop rotations, which is essential in maintaining the long-term sustainability of agricultural practices [132]. By advising on which crops to grow in which fields, and in what order, cooperatives can contribute to improving soil health, reducing pest infestations, and boosting yields. Partnering with other farmers is another potential strategy to ensure the long-term economic viability of farms, and boost profitability [133]. Cooperatives also offer support in marketing ecologically grown produce, which helps to offset any additional production expenses [134]. Furthermore, cooperatives can provide valuable support to farmers, by improving their access to PPPs, and helping them use these products safely and efficiently, while meeting food quality requirements [135]. Overall, implementing cooperatives and participatory partnerships among farmers can help address the challenges posed by seed overuse and pests, while promoting economic viability and profitability in farming operations.

Minimizing the wheat loss at harvest requires improvements in the process' efficiency, through providing farmers with advanced machinery, enforcing technical inspections, and offering training to the operators. Cooperatives play a significant role in improving access to agricultural equipment among small-holder farmers, as they rely more on cooperative machine use [136]. By pooling their resources and expertise, cooperatives can purchase or lease machinery and equipment that can be shared among members, reducing costs, and increasing efficiency [137]. However, a major hurdle to implementing mechanization on small-scale farms in Fars appears to be a lack of consensus among farmers on the joint use of agricultural machinery.

"Their [small-holder farmers'] farm areas are small, which hinders mechanization in the field. Most of these small-holder farmers cannot reach an agreement to merge their lands for easier mechanization." (Seed producer)

The study conducted by Sutherland et al. [138] in European countries demonstrated that, despite the relatively favorable financial circumstances of farmers in affluent nations, cooperatives play a vital role in enhancing agricultural productivity, and mitigating the challenges faced by small-scale farmers. Through democratic procedures, cooperatives can create a consensus among small-holder farmers [139], allowing for mechanization in a large set of small fields. This can facilitate the use of modern combine harvesters that are designed for large farms.

"The new combine harvesters are designed for large farms; as there are many small farms, it does not make sense to use them." (Co-op CEO)

Additionally, cooperatives can negotiate favorable pricing and financing terms with equipment suppliers, reducing the financial burden on individual farmers [140,141]. This results in improved access to agricultural machinery and equipment, which increases productivity, reduces labor costs and, ultimately, improves farmers' livelihoods [142]. Furthermore, cooperatives can provide training and technical assistance to members on the proper use and maintenance of equipment, further increasing their effectiveness and productivity [143]. This can help to alleviate the problem of the shortage of skilled combine harvester operators that was discussed earlier.

While agricultural cooperatives are active in Iran, particularly in Fars province, the present study implies that there is potential for improvement, and it is necessary to investigate the factors contributing to their suboptimal functioning, and strategies to enhance their performance. It is crucial to note that the effective functioning of cooperatives depends on the presence of a strong political will and support. The governance and independency of cooperatives can be heavily influenced by the political structure of a country [144].

In terms of its definition, a cooperative, at its very core, is characterized by autonomy and democracy [145]. Cooperatives' foundation relies on having a political system that protects and guarantees the freedom of association, democratic governance, and independence, through a transparent legal and regulatory framework and accountability [145]. Authoritarian regimes, by exerting central control and political interference over the economy, restricting access to resources, and lacking transparency in economic policies and decision-making processes, can impede the ability of cooperatives to operate freely and effectively [146–148].

Throughout history, cooperatives have been abused by those in power, as a tool to impose control over the populace, and promote autarky [149,150]. However, the presence of cooperatives can be deemed beneficial even under authoritarian regimes. Dillon examined three divergent viewpoints on the history of cooperatives in Ukraine, and concluded that, despite the constraints imposed by authoritarian regimes, cooperatives can still generate social benefits [151]. Nevertheless, while cooperatives operating within authoritarian governments may yield certain societal benefits, totalitarian regimes are ultimately destined for economic failure [149]. Examples of such may include the destruction of rural cooperatives, as well as economic and agricultural breakdowns under dictators such as Benito Mussolini in Italy, Francisco Franco in Spain, and Ioannis Metaxas in Greece [149,150,152]. On the other hand, civil societies can strengthen the political governance of cooperatives, by engaging in progressive activities and reformist initiatives. The case of Vietnam exemplifies the significant potential of civil society and nonprofit institutions in constraining the extractive power of an authoritarian regime [153]. Likewise, cooperatives, with their solidarity-orientated nature, are capable of, as Freyburg [154] puts it, 'planting the seed of change', to yield a greater productivity.

4. Conclusions

The outcome of the present study portends an alarming trend in wheat production in the Fars region, which not only causes food loss, but also endangers biodiversity, soil fertility, food security, and human health. The long-term intensive cultivation of demanding cash crops, such as wheat, maize, and rice in the region has led to a reduced production efficiency and farming challenges that cause enormous wheat loss, due to excessive seed use and difficulties in pest control. The swift deterioration in the agricultural landscape in Fars demands an urgent and pivotal shift toward implementing more sustainable and ecological farming strategies. Practices such as diversified rotational cropping, ecological and integrated pest management, and targeted and efficient PPP application can increase seed utilization efficiency, decrease plant diseases and, ultimately, lead to reduced on-farm losses.

Through the implementation of the aforementioned sustainable farming practices, there is potential for a regeneration of soil fertility and improvement in agricultural productivity. This, in turn, can contribute to an increased seed utilization efficiency, and would enable farmers to employ a reasonable amount of seed; for example, the range of 170–180 kg per hectare recommended by the Agriculture Organization of Fars. The adoption of such strategies is crucial to addressing the current alarming trend in wheat production, mitigating biodiversity loss, enhancing food security, preserving soil health, and safeguarding human well-being in the Fars region.

To address the issue of harvest loss, it is crucial to prioritize increasing the access to advanced and optimized equipment, through financial support for farmers, promoting collective cooperation, enforcing timely technical inspections, and offering educational opportunities for both farmers and combine operators. The use of outdated and poorly maintained equipment, as well as a lack of proper training and supervision of harvester operators, exacerbates the problem. This results in significant financial losses for farmers, and can have a negative impact on the overall wheat production and food security in the region.

Harvest loss is a significant challenge faced by farmers worldwide, resulting in substantial economic losses and food scarcity. Addressing this challenge is essential for improving global food security, and enhancing farmers' livelihoods. Achieving this goal requires a comprehensive approach that includes implementing a combination of solutions to the food production structure, such as improved crop varieties, better harvesting techniques, fair compensation for combine operators, and adequate training and support for farmers. In light of the current challenges regarding wheat production in the Fars province, future studies should direct their attention toward identifying strategies aimed at enhancing the socio-economic aspects of wheat production, while simultaneously engaging in the development of machinery that is customized for the region's unique agricultural landscape.

Overall, the present study sheds light on the extent and underlying causes of wheat on-farm loss in the Fars province, providing critical knowledge that could serve as the foundation of targeted interventions and policies aimed at reducing food loss, promoting sustainable farming, and improving food security. While the study's primary focus is on a specific geographic and social context, its deep and comprehensive methodical exploration confers the applicability of the results to a broad range of researchers, practitioners, and policymakers. This paper imparts valuable insights to other regions and countries that endeavor to augment the efficacy of agricultural production and economic gains by exploiting natural resources through intensive farming, disregarding the long-term repercussions.

While the current study drew upon qualitative information to explore the phenomenon of on-farm wheat loss, it is imperative that future research also focuses on quantitative approaches. Quantifying wheat loss on farms would be crucial to establishing data comparability across regions and countries, and thereby allowing for more comprehensive assessments of the food loss problem. Moreover, a quantitative investigation would provide an empirical basis for monitoring the efficacy of food-loss reduction plans. While qualitative studies can be illuminating and offer valuable insights, the benefits of numerical evidence in policy-making and intervention strategies cannot be understated.

In conclusion, the findings of this study underscore the critical role that cooperatives can play in addressing on-farm food loss and agricultural inefficiencies. By promoting collective action and knowledge-sharing among small-scale farmers, cooperatives can reduce food loss, encourage sustainable farming practices, and enhance agricultural productivity. To ensure that farmers' cooperatives can thrive, governments must adopt a supportive approach. In Iran, this can be achieved through the provision of cooperatives, with educational opportunities, and financial assistance through subsidies and low-interest loans with extended grace periods. This would foster a healthy and competitive market, reducing central control and interference, and strengthening democratic decision-making processes and cooperatives' authority and freedom.

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Chapter 4: Article 3

Title of the Article: Comparing Lab-Measured and Surveyed Bread Waste Data: A Possible Hybrid Approach to Correct the Underestimation of Household Food Waste Self-Assessment Surveys

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Abstract

Among the common methods of quantifying household food waste, direct measurement is regarded as infeasible due to its prohibitive costs, and self-assessment methods tend to underestimate the actual values. This paper aims to propose a methodological approach to reach a compromise between feasibility and accuracy. Bread was studied, since it is a relatable example. The self-assessment method was used to survey 419 households in Shiraz, Iran, during 2019 to estimate household bread waste (BW) and to identify waste-causing consumption recipes (WCCR). These WCCRs were replicated in the lab, and the resulting BW was measured. The underestimation in the self-assessment method was revealed by comparing the survey results with the lab measurements. The underestimation ratio (UR) ranged between 1.24 and 1.80. The pattern of difference between these four bread types was similar among the survey and lab data. In conclusion, the lab measurements may estimate BW caused by the WCCRs more accurately. This suggests that URs can be applied to correct the underestimation in self-assessment surveys. Such an approach could provide the basis for further research on the development of cost-effective methods to quantify waste across a variety of food commodities.

Keywords: quantification methodology; bread waste; subjective assessment; food waste and loss; food waste evaluation; food waste measurement; household food waste

1. Introduction

In recent years, increased attention has been paid to food loss and waste (FLW) at national and international levels [1–4]. The United Nations' (UN) Sustainable Development Goal 12.3 requires all nations to cut their food waste at consumer level by half by 2030 and to mitigate food loss along production and supply chains [5]. Several countries passed laws and adopted plans aiming at FLW reduction. In Germany, for example, the Federal Ministry for Food and Agriculture [6] adopted a national strategy for the reduction of food waste, starting in 2019. Japan's parliament even passed a law in 2019 for reducing FLW [7].

However, the success of such plans is highly dependent on thorough monitoring and evaluation of their progress. For this purpose, valid and reliable data on FLW play a crucial role, and quantifying FLW is a necessary prerequisite [8]. The availability of up-to-date primary comparable data on FLW remains a serious challenge [9]. The reason might be embedded in the lack of standard measuring methods or inhomogeneity in FLW definitions and recognitions [8,10]. In a systematic review, van der Werf and Gilliland [11] found high variability in FLW estimations (95.6–300.0 kg/capita/yr). They argued that, in addition to geographical factors, methodological and definitional differences could cause the high variation.

According to the report on Global Food Losses and Food Waste published by the Food and Agriculture Organization of the United Nations [12], food loss refers to food's quantitative deduction from farms to market (pre-consumption stages), whereas food waste alludes to discarding food at retail and consumer levels (consumption stages). Hereafter, the terms "food loss" and "food waste" are used in conformation with these definitions.

Compared to food waste estimation, quantifying food loss seems to be less complex, with the use of food balance sheets [13] and analysis of the mass flow of certain food commodities at production, storage, transportation, processing, and distribution stages [12,14,15]. Expectedly, gaining access to robust data on food loss is easier in countries with well-developed food supply chains and transparent inventory [16]. For example, in the European Union (EU), the food traceability law, Article 18 of Regulation 178/2002, requires the member states to maintain precise records of food and feed products "at all stages of production, processing, and distribution" [17]. This law can facilitate the material flow analysis to quantify FLW throughout the food supply chains. To quantify potato loss in Switzerland, Willersinn et al. [2] first used secondary data from the governmental and institutional sources, then surveyed producers and stakeholders along the different segments of the supply chain to cover the missing data.

However, regarding food waste, establishing proper quantification methods to gain more precise estimations remains essential, especially considering the high contribution of consumption stages to the total FLW, which is approximately 6–20% in developing countries and 26–40% in developed countries [12]. Aside from the methods used to estimate waste in foodservice sectors that bear low ambiguity [18,19], limitations and complexity of household food waste estimation methods seem to remain crucial [2,16]. Therefore, food waste quantification at household level has become a central issue [16].

In spite of the attempts to establish one standard method for food waste estimation in households, such as the efforts within the FUSION [20] and REFRESH [21] projects, researchers still implement various approaches depending on data availability, context, and settings of their studies. Both of the projects mentioned aimed to develop unified definitional frameworks and standard quantification methods for FLW. However, these projects belong to the EU and focused on the food waste issue in the EU. Although the applicability of the methods developed within these projects was satisfactory for some European studies [8,22], implementation of such methods might be challenging in some non-European countries where sufficient research budgets are scarce, e.g., in developing countries. In general, the food waste data gap in developing countries is wider compared to high-income countries [16]. The reason might be that food waste quantification methods, especially for identifying domestic food waste, are costly. Therefore, in order to fill the data gap, it is critical to develop methodologies that are both accurate and affordable particularly in low-income countries [16,23,24].

Elimelech et al. [24] categorized previous methodologies of food waste evaluation for households into two approaches: (1) objective or "food waste direct measurement" that is based on physical analysis of domestic food waste and (2) subjective or ''self-assessment" that includes using consumer diaries or recall questionnaires. Both of these approaches have limitations and advantages. Although direct measurements may yield more precise numbers [25], they are expensive and challenging to carry out [24]. In many study settings [26], it is difficult to achieve large enough sample sizes using direct measurement methods, due to the high costs and efforts involved. Although self-assessments may be more convenient to obtain larger sample sizes and cover more population segments, they bear high uncertainty and subjectivity [16,23,25,27], and so implementing them might be unjustified [24,26]. Few researchers have tried to increase the reliability of household food waste data by implementing hybrid methods consisting of both direct measurement and self-assessment surveys [24,26]. Elimelech et al. [24] compared objective and subjective methods by conducting food waste physical direct measurement and food expenditure survey as the objective methods and questionnaire survey as the subjective method simultaneously. Moreover, Quested et al. [26] compared direct measurement and food waste diary. Both of these studies concluded that direct measurement is more accurate than self-assessment. However, considering the impracticality of direct measurement in many contexts, improving self-assessment surveys seems to be more relevant.

The major flaw in self-assessment methods is considered to be underestimation [20,23,24,28–30]. The studies that implement diaries mostly understate the amount of waste [23,28,29], because respondents are more mindful about the matter [20,26,28]. Underestimation also occurs in the surveys using recall questionnaires, due to difficulty in remembering the waste amount or even lack of awareness regarding waste occurrence [30]. Some respondents' lack of honesty and openness can also explain the inaccuracy in the results of both diary and questionnaire surveys [20].

Although previous self-assessment studies might have failed to provide accurate estimations of food waste amounts at household level [16], a considerable amount of literature has successfully identified the reasons behind food wastage at the household level [2,31–35]. These reasons can include attitudes to food shopping, storage management [34,35], personal preferences [36], beliefs, lifestyle, waste awareness, and perhaps, a particularly crucial point is food preparation/consumption methods [2,31–33], henceforth referred to as "consumption recipe" (CR).

Certain CRs could lead to avoidable food wastage due to the discarding of edible parts of food [37]. An example of such CRs is the consumption of citrus fruits as juice, or only pomace, or even pomace and zest, which generates various amounts of avoidable food waste [38]. Another example is that some athletes discard egg yolk before consumption [39]. More examples could be obtained in different geographical and cultural contexts, most of which could be replicated in a lab with possible practicality of measuring the resulting waste.

The goal of this paper is to propose a new methodological approach to reach a compromise between accuracy and feasibility by increasing the validity of self-assessment survey data while considering executive costs and complications. Accordingly, the study aimed to examine the feasibility of measuring avoidable food waste resulting from waste-causing CRs (WCCR) in the lab and to discuss the possibility of using the lab results to correct the underestimation of self-assessment surveys. The research focused on identifying the WCCRs that contribute to avoidable food waste that is measurable in a lab.

As previously mentioned, most studies on FLW have been conducted in developed countries [16]. Therefore, as a developing country with a dynamic young population and a transitional agri-food system, Iran was chosen as the target region. Bread was used as an example to test the method. The reason for choosing this food commodity lies in its importance as the main staple food in Iranian culture and cuisine [40]. Choosing bread facilitated reaching a relatively large number of households who could easily relate to the study's topic. Shiraz was chosen as the target location, as it is the capital of the major wheat-producing province, Fars. Shiraz is also the fifth most populated city in the country, with about 1.87 million inhabitants [41], which provided favorable possibilities to conduct this study in an urban setting. The main focus of this study was solely on the methodology of household food waste measurement. The discussion of bread waste (BW) amount falls outside of the scope of this paper and will be provided in a separate article.

2. Materials and Methods

2.1. Overview

This section provides information on how the questionnaire survey and the lab measurements were conducted. Moreover, the statistical analysis methodology used to compare the survey outcome with the lab results is described. The final part of this section outlines the underestimation ratio (UR) calculation.

2.2. The Questionnaire Survey

A face-to-face questionnaire survey was conducted from December 2018 to August 2019 in Shiraz, Iran. A total of 419 households were studied. Each household was defined as one sampling unit, referring to a group of two or more individuals living in one house and sharing food and its costs. The study was carried out in conformity with the Declaration of Helsinki. The survey protocol was certified by the Ethical Committee of the Shiraz University of Medical Sciences, with the code IR.SUMS.REC.1397.595. In all cases, participants' written consent was obtained before the onset of interviews.

The sample size was calculated based on the total number of households living in Shiraz and according to the following equation [42], while adding about a 10% buffer.

$$\mathrm{n} = \frac{NZ^2P(1-P)}{(N-1)E^2 + Z^2P(1-P)} = 384,$$

where n identifies the sample size;

N is the population (households in Shiraz = 477,916 [41]);

Z denotes the Z score based on the level of confidence (for a level of confidence of 95%, Z = 1.96);

P stands for the expected prevalence or proportion (assumed to be 50%);

E is an abbreviation for the margin of error (assumed to be 5%).

Final sample size = n + ~10% = 419

In order to achieve homogeneity in the geographical distribution of samples, the households were selected based on a three-stage selection approach consisting of, firstly, stratified sampling, secondly, cluster sampling, and finally, systematic sampling.

Data were gathered using a researcher-made questionnaire. In order to evaluate the respondents' comprehension of the questions, the questionnaire was tested beforehand by interviewing 22 samples outside of the study population. The questionnaire included questions regarding bread purchase, wastage, and CRs of the households. The person responsible for food preparation and management in the household was interviewed.

The bread types included in this study were baguette, burger bun (hereafter referred to as bun), a baguette-like 20-cm bread locally known as sandwich bread, and a traditional Iranian flatbread called sangak. Each bread type was available in two categories at the food market in Shiraz, namely traditionally baked and machine-made for sangak, and fresh and packaged for the others. Packaged bread was defined as factory-produced bread with plastic packing and expiry date. For the sake of simplicity, each category of a bread type is referred to as bread item (e.g., fresh baguette). Further specifications of the studied bread can be found in Iranian National Standards Organization (INSO) [43,44] and Karizaki [40].

The respondents were asked to provide an estimation of the number of bread pieces usually purchased when typically shopping for the household, as well as the amount of waste of the same purchase, using specific portion sizes, namely a 7-cm piece for baguette and sandwich; half a piece for bun; and one palm as a scale for sangak. The definition of waste was explained to the respondents as parts of bread not used for human consumption. This means stale bread used for cooking was not considered as waste, but bread which was disposed of with household garbage or fed to animals was accounted for as waste. The reported purchased bread pieces and the respective waste amount values were converted to gram using the locally validated domestic guideline for food measures [45]. The waste was calculated based on the mass relation of the wasted amount compared to the purchased amount, expressed in percent. In addition, the respondents were asked to describe the CRs they apply for each bread item. A hypothetical example is given below for further clarification.

Interviewer: How many pieces of baguette would you typically purchase for the household without considering special occasions?

Respondent: Two pieces.

Interviewer: How much of these two pieces would be normally wasted in your house? Please express your estimation using a 7-cm baguette piece as an index.

Respondent: Normally two 7-cm pieces would be wasted.

Interviewer: How do you consume baguette? Do you consume the bread as a whole or do you discard some parts before consumption?

Respondent: We normally discard the inner crumb before consumption.

In the given example, the amount of purchased baguette and the waste amount would have been calculated to be 310 and 70 g, respectively, given that a complete baguette piece weighs 155 g and each 7-cm piece is 35 g [45]. Accordingly, the baguette waste amount for this hypothetical household would be 22.6%. Moreover, inner crumb discarding would be identified as the WCCR for this household. Similar questions were also asked regarding the other bread types. In cases where the response did not conform to the validated portion sizes, a nutritionist converted the answers to gram using dietary assessment exchange lists. If the response was too subjective and conversion was not possible, the case was excluded from the analysis.

2.3. Lab Measurement

The WCCRs were identified using the survey outcome. Measuring the waste amount resulting from the WCCRs was carried out as follows: bread pieces were acquired from randomly selected bakeries and supermarkets in Shiraz, and the WCCRs for all bread types (except sangak) were replicated with the help of 10 randomly chosen untrained panelists. The bread pieces were weighted first intact—total mass of the whole bread—and then after replicating the WCCR and without the discarded parts, using a lab scale with an accuracy of two decimals. The difference indicating the waste was expressed as a percentage of the total mass. Sangak sampling and recipe replication were treated differently, because sangak's WCCR is associated with bread quality. Further information about the WCCRs is provided in the results section.

A random selection of a total of 39 sangak pieces (three pieces per shop) was purchased from five traditional sangak bakeries and eight machine-made bakeries in Shiraz. Dough that was not adequately baked was removed from the perimeter of each sangak bread piece. For the other three bread types, 30 bread pieces of each bread item were randomly purchased from different bakeries and supermarkets and then pooled. Packaged baguette was not available at the time of the lab study due to seasonal scarcity. Ten randomly selected untrained panelists were asked to apply the WCCRs. Each panelist was given three bread pieces from each pool. This meant that each panelist applied WCCRs on three pieces of each bread item.

2.4. Statistical Analysis

The software used to analyze the data was SPSS Version 25 [46]. One-way ANOVA and Tukey's post-hoc tests were conducted to compare the waste percentage mean of the four bread types from the same data source (i.e., lab measurement and questionnaire survey). A nominal *p*-value of 0.05 or lower was considered statistically significant.

The two-sample *t*-test was applied to compare the survey data with the lab measurement results, assuming unequal variances. Finally, the URs were calculated as the quotient of the mean values for waste amount measured in the lab and the mean values of the waste amount reported in the survey.

With the use of boxplots, all observations were thoroughly checked for outliers. Cases with a value of three interquartile range (IQR) or higher were recognized as extreme outliers, whereas values more than 1.5 and less than 3 IQR were identified as normal outliers [47]. No outlier was detected among the lab measurement data. However, in the survey datasets, one extreme outlier was found for sangak and baguette. The extreme outliers were excluded for the comparison with lab measurement results, because after referring to the questionnaires, it was revealed that these extreme outliers were the households that reportedly throw away, not only parts of the bread but also the whole bread, because if it is stale it is considered inedible. Such samples could not be used to represent the waste caused by WCCRs. Normal outliers remained in the data. The test was also run without the normal outliers for extra assurance, which did not change the significance in any of the comparisons. The extreme outliers were not excluded from the data used for presenting the total waste in the survey, because extreme high wastage due to the disposal of whole bread can be considered legitimate and must be included in the analysis.

3. Results

3.1. Overview

In this section the questionnaire survey outcomes are presented, followed by the results of the comparison between the survey and the lab measurement data.

3.2. Wheat BW of the Households

Based on the 873 responses from the 419 respondents to the question on the waste amount, the total wheat BW was estimated at 3.64% with a standard deviation (SD) of 6.83%, regardless of type and category. Table 1 shows the mean percentage values for BW, classified on the basis of bread type and category. It is apparent from this table that similar waste proportions were noted in the same categories of baguette, bun, and sandwich, while sangak reportedly had lower numbers. The Tukey test revealed significant differences between sangak waste and any other bread type from the same category (*p*-value < 0.001), while no significant difference was found among the other three bread types within the same category.

Table 1. Mass-percentage mean (standard deviation) of total waste for different bread items.

Bread Category	Baguette	Bun	Sandwich	Sangak [1]
Fresh	5.58 [7.85]	4.09 [5.97]	4.65 [8.64]	1.86 [5.15]
Packaged	6.07 [6.34]	7.91 [8.06]	8.42 [9.15]	2.65 [5.76]
Total	5.72 [7.43]	5.17 [6.80]	5.47 [8.86]	2.24 [5.46]

[1] For sangak, the categories are traditionally backed and machine-made, instead of fresh and packaged, respectively.

3.3. Bread Purchasing Habits and the Ability to Recall Waste Amount and CRs

The questionnaire survey revealed that not all of the studied households typically purchase all eight bread items. Moreover, not all of the respondents of those households that purchase certain bread types were able to recall the waste amount or CRs. Table 2 shows the typical wheat bread purchasing habits in the households as well as the respondents' ability to recall the waste amount and CRs. Overall, the respondents had less difficulty in remembering CRs than the waste amount, except in the case of sangak. A high rate of respondents of the households who typically purchase sangak (95.1% for traditionally baked and 98.8% for machine-made) were able to recall the waste amount, while this number ranged from 53.2% to 66.4% for fresh bun and fresh baguette, respectively. Contrarily, the ability to recall the CR was high for all bread items ranging from 91.5% to 93.5%. A small number of interviewees could recall the waste amount but were unable to recollect the CRs. Generally, the tendency towards purchasing fresh bread seems to be higher in comparison to packaged bread. Sangak seemed to be the most popular bread type among the bread types in this study, while bun was found to be the least popular.

Table 2. Number (frequency) of households presented based on their typical bread purchase habits, and the respondents' ability to recall waste amount and CR.

Attitudes to Bread Purchasing and Consumption	Baguette		Bun		Sandwich		Sangak	
	f	p	f	p	f	p	t	m
Typically purchasing the bread item	134 [32.0%]	54 [12.9%]	124 [29.6%]	43 [10.3%]	211 [50.4%]	59 [14.1%]	267 [63.7%]	245 [58.5%]
Able to recall the waste amount	89 [21.2%]	35 [8.4%]	66 [15.8%]	26 [6.2%]	126 [30.1%]	35 [8.4%]	254 [60.6%]	242 [57.8%]
Able to recall the CR	123 [29.4%]	50 [11.9%]	116 [27.7%]	40 [9.5%]	197 [47.0%]	54 [12.9%]	249 [59.4%]	229 [54.7%]
Able to recall the waste amount but not the CR	5 [1.2%]	2 [0.5%]	6 [1.4%]	2 [0.5%]	6 [1.4%]	3 [0.7%]	14 [3.3%]	16 [3.8%]

CR = Consumption recipes; *f* = fresh, *p* = packaged, *t* = traditionally baked, *m* = machine-made.

3.4. CRs

In response to the question "how do you normally consume bread in your household?", three major responses were elicited: (1) consuming bread as a whole, (2) consuming bread after discarding the crumb (unbaked perimeter discarded in the case of sangak), and (3) unable to recall the CR. Crumb discard refers to removing the spongy inner texture of bread after cutting the longitudinal section of a bread piece such as baguette. Unbaked perimeter discard occurs when a consumer disposes unbaked or semi-baked dough from the outer perimeter of a flatbread piece such as sangak. However, consuming bread as a whole does not imply that consumers do not discard parts or the whole pieces of bread. The consumers who reported this CR might still throw away stale bread, non-specific parts, or leftovers, hence contributing to the waste percentages previously reported (see Table 1).

Figure 1 illustrates the frequency of the major CRs for the eight bread items among the surveyed households. Overall, the majority of the study population discarded the crumb before consuming baguette, bun, and sandwich bread, whereas most of the sangak consuming households reported that they consume this bread as a whole. Packaged baguette had the highest share of crumb discard (67%), whereas at least half of the households who consume other bread items (with the exception of sangak) also discard the crumb. In more than 80% of the households, there was a tendency to consume sangak without discarding any specific parts. Only a small share of respondents was unable to recollect the CRs, as previously indicated differently in Table 2.

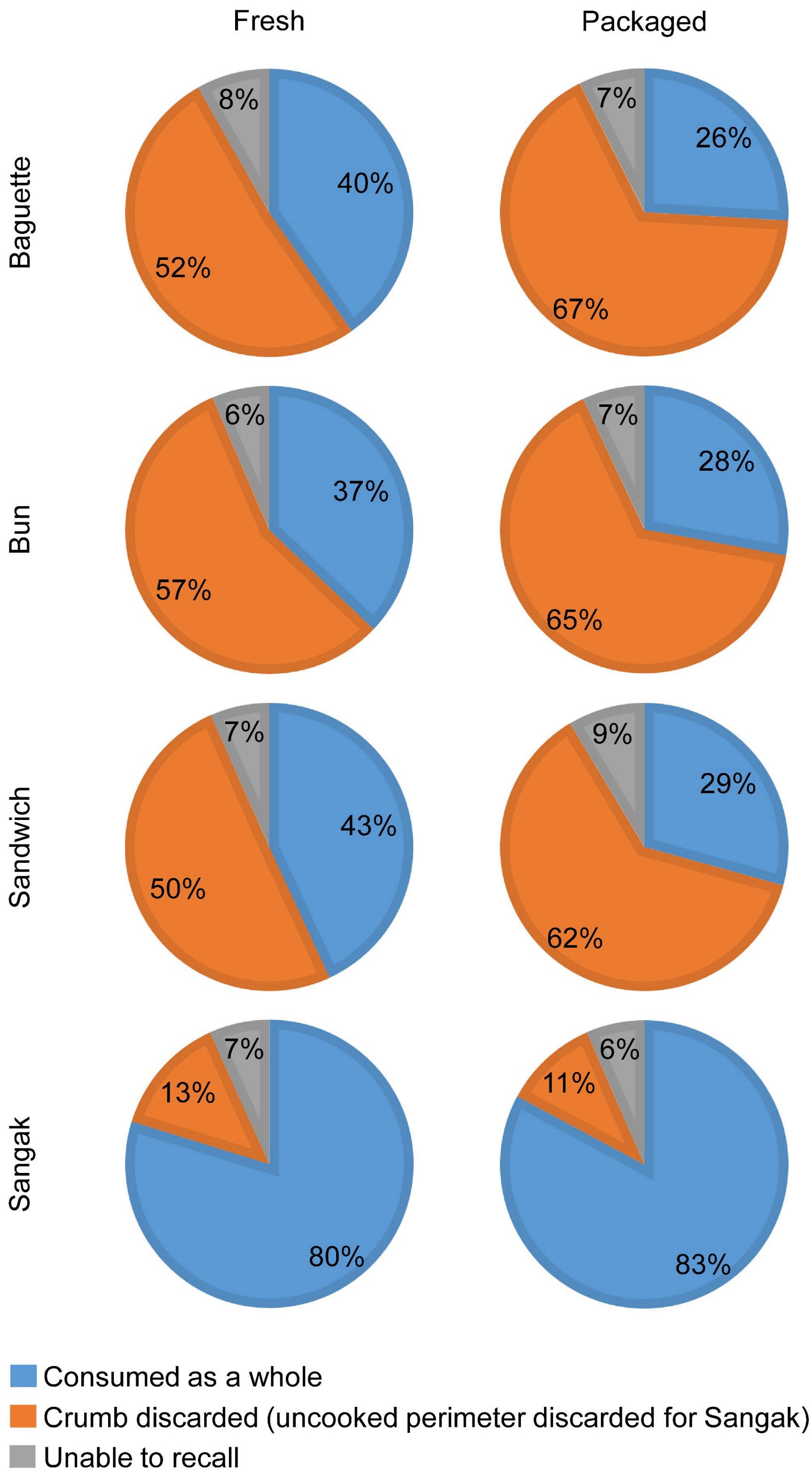


Figure 1. Frequency of consumption recipes (CRs) among consumers of the eight bread items.

3.5. Survey and Lab Measurement Data Comparison

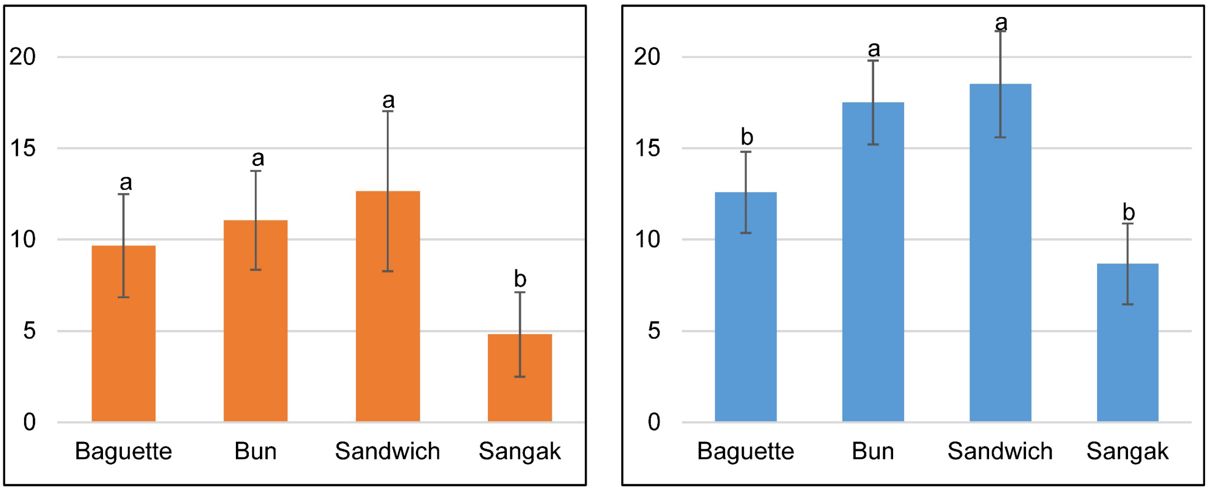
Discarding unbaked perimeter from sangak and discarding crumb from the other three bread types were identified as the main WCCRs that were to be replicated in the lab based on the methodology described in Section 2.3. Table 3 presents the mean percentage values of BW directly measured in the lab as well as the waste calculated based on the responses from the households in which the typical WCCR was unbaked perimeter discard for sangak and/or crumb discard for the others.

Table 3. Comparison between survey and lab measurement waste percentage obtained from the data on discarding bread crumb (unbaked perimeter for sangak).

Bread Types	Lab Measurement			Household Survey			Sig. (2-Tailed)	UR
	n	Mean	[SD]	n	Mean	[SD]		
Baguette	30	11.28	[3.62]	45	9.12	[5.29]	0.039	1.24
Bun	56	17.51	[4.60]	26	11.06	[5.41]	0.000	1.58
Sandwich	60	18.51	[5.81]	44	12.65	[8.77]	0.000	1.46
Sangak	20	8.67	[4.43]	50	4.81	[4.63]	0.002	1.80

Moreover, Table 3 indicates the results of two-sample t-tests conducted to compare the waste of the same bread type measured in the lab and estimated in the survey. Additionally, this table lists the UR for each bread type, indicating the ratio of measured waste values measured in the lab to the waste values reported in the survey. The two-sample t-test revealed that the waste estimated based on the survey results was significantly lower than the waste measured in the lab for all bread types. The mean values calculated using the lab measurement data were 1.24–1.80 times higher than those estimated according to the questionnaires, which is another way of explaining what the UR represents.

A closer inspection of the results revealed a similar difference pattern among the mean percentage values for the waste of different bread types of the same data source. Figure 2 visualizes the difference patterns between the different bread types among the lab and the survey data. Looking at the lab measurement bar graph, it is clear that sandwich was the highest, closely followed by bun and baguette, while sangak has the lowest mean value. Similar pattern can be seen in the survey results. However, in the lab dataset, the waste values for bun and sandwich waste values were significantly higher compared to baguette and sangak. Additionally, analyzing the questionnaire survey waste data did not show any significant difference between sandwich, bun, and baguette, while sangak waste was significantly lower compared to the other three bread types.



(a) **(b)**

Figure 2. Graphical representation of the waste percentage means for different bread types: (a) illustrates the waste percentage of the four bread types according to the self-assessment survey and (b) shows the waste mean values for different bread types measured in the lab. Different letters on top of bars with the same color indicate a significant difference within each graph at an alpha level of 0.05 according to Tukey's post-hoc test.

4. Discussion

The inconsistency in the available data on household food waste is associated with the lack of standard quantification methods [48]. As explained in Section 1, among food waste quantification methods at household level, the implementation of objective approaches (physical measurement) might seem unjustified in large-scale settings due to their high cost and labor requirements [16,49]. On the other hand, the validity and accuracy of subjective methods (self-assessment) are uncertain, although their implementation may be more convenient [24].

Generally, in the self-assessment approach, the accuracy of the respondents' waste estimates is still questionable [28,30]. Nonetheless, Elimelech et al. [24] argued based on Galton's "the wisdom of the crowd" [50] that although individuals might underestimate food waste, the overall outcome could be "quite good". However, they also made clear that using self-assessment methods to evaluate household food waste cannot be justified due to underestimation. Elimelech et al. [24], along with other researchers, proposed further investigations for improving such methods [26,30,51]. The fact that self-assessment surveys highly depend on the respondents' ability to recall the amount of food waste undermines the accuracy of their outcome [16]. However, although recalling the waste amount is challenging for the respondents, they might remember the CRs of certain food commodities more simply.

As one of the study objectives was to identify the WCCRs that may lead to discarding parts of bread, the focus of this study was on the respondents' ability to recall not only the waste amount but also the CRs. The results unveiled that the number of respondents who were able to recall the recipes were more than those able to recall the waste amount. Meanwhile, a small number of respondents were able to recall waste but not the recipe. This means respondents could remember the CRs easier than the waste amount. These findings are in good agreement with the work of Richter and Bokelmann [52], who found the self-assessment approach suitable for recollecting precise food waste behavior data. These results are also broadly consistent with the argumentation in Section 1 [2,31–33]. That behavioral information is easier to remember compared to the food waste amount could be explained by the differences in the individuals' ability to recollect data of different natures [53]. Dex [53] explained that people's ability to remember qualitative information is higher than their ability to recall information of quantitative nature.

As described in Section 1, different factors are associated with food wastage in households, with CR being an important one [2,31–33]. Therefore, in this study, the major CRs which could lead to discarding parts of bread pieces and consequently bread wastage were identified as WCCRs. The results showed that the major WCCRs among Shirazi households were discarding the inner crumb of baguette, bun, and sandwich bread, and discarding the unbaked perimeter of sangak. It is unclear why some consumers in Shiraz discard the inner crumb of bread. To the best of our knowledge, no scientific research has addressed this matter. However, it can be speculated that consumers discard the crumb due to cultural reasons, or low bread quality and palatability.

The households were grouped based on their CR, and the BW mean was calculated for the households in which the WCCRs were implemented. Predictably, the mean waste values caused by the WCCRs were higher than the overall calculated waste. All households may waste bread due to storage or purchasing mismanagement [2,31–33]. However, those households with the habit of discarding parts of bread contribute to more waste than the households that usually consume the bread as a whole. The main purpose of this study is to examine the possibility of measuring the waste resulted from the WCCRs. Therefore, we attempted to replicate the WCCRs in the lab and directly measure the waste amount.

The lab measurement results were significantly higher than the self-assessment estimations. This concurs well with previous studies that made comparisons between objective and subjective methods [23,24,26]. By "comparing diaries and waste compositional analysis" in a study on household waste of all food groups, Quested et al. [26] found the underestimation in the self-assessment method to be between 7% and 40% (URs of 1.08 to 1.67). Meanwhile, the URs in the present study ranged between 1.24 and 1.80. The concurrence of our results with the work of Quested et al. [26] could suggest that the objective measurement (lab measurement) used in the study resulted in more realistic estimations compared to the subjective method (survey).

Moreover, looking at the differences between the four bread types, it is clear that the difference pattern among BW mean values is similar in survey data and lab outcome. In the survey, sangak was found to have the least waste amount compared to the other three bread types. Lab measurement yielded similar results. This confirms previous findings by Irani and Yazdi-Samadi [54]. The lower waste of sangak can be explained by the fact that most of the households consume this bread type as a whole. Further examinations revealed a similar difference pattern among the survey results and the lab outcomes. In both datasets, sangak had the lowest waste, followed, respectively, by baguette, bun, and sandwich. Assuming the underestimation to be the only factor manipulating the survey results, it could be expected that the real BW mean values should have had the same difference pattern among them, but higher. Therefore, the rational assumption is that the real values are closer to the ones measured in the lab. This may provide additional support for the reliability of the lab measurement results in the present study.

An option for improving the subjective methods might be using URs to correct the underestimation in self-assessment data. Using under/overestimation ratios for correcting data is a well-known approach in data analysis. For example, in nutritional studies, under/over-reporting commonly occurs in recall-based dietary energy intake assessments [55–57]. Adjusting these data flaws by means of under/overestimation factors is a well-established method in nutritional sciences [58]. Similarly, using a UR as a tool for correcting the underreporting in household waste self-assessment data might provide a more realistic evaluation. For instance, the UR for bun was 1.58, while the overall waste for this bread—without taking the CRs into account—was estimated to be 5.17% based on the survey. Inflating this number by the factor of 1.58 results in a BW mean of 8.17%. The inflated value is more in agreement with the 13% BW reported by Edjabou et al. [59], who directly measured food waste mass in Danish households.

Based on the approach implemented by Xue et al. [16], we created Table 4 to present the strengths and weaknesses of the methods used for quantifying household food waste in contrast to a hybrid method that consists of self-assessment and lab measurement. As can be seen, the direct measurement method yields the most accurate results. However, this method could be irrelevant in many contexts, because it is cost- and labor-intensive [26]. Implementing a self-assessment method is more feasible, but it does not generate accurate results [24]. Based on our experience, replicating WCCRs and measuring the waste is feasible, and it can help to increase the accuracy of the self-assessment method. Both direct measurement and lab measurement are highly objective. Considering the uncertainty of self-assessment and the need to use objective and subjective hybrid methods [24], implementing a method similar to the one used in this study as an objective method would be a better alternative when compared with the costly method of direct measurement.

Table 4. Description of strengths and weaknesses of the methods used for household food waste quantification.

Method	Cost	Accuracy	Feasibility	Objectivity
Direct measurement	•••	•••	•	•••
SA survey	•	•	•••	•
SA survey and lab measurement hybrid	••	••	•••	••

Cost refers to both monetary and labor costs; SA = Self-assessment; • = Low; •• = Medium, ••• = High.

Accordingly, the description of the method that this paper proposes can be discussed as follows:

1. WCCR identification: The first step is to identify a particular food commodity with WCCR. The necessary information for this purpose could be captured by carrying out a pilot survey by means of a qualitative questionnaire. The criteria for identifying the WCCR are (a) a certain level of familiarity with the chosen food commodity has to exist among the target consumers (e.g., the food commodity is commonly consumed by the majority of the understudy households); (b) the WCCR has to be replicable and should commonly exist among the target consumers. For instance, bread in the context of the present study was commonly consumed among the surveyed households. Moreover, most of the consumers in Shiraz were familiar with the WCCR (e.g., discarding the inner crumb of baguette), which was also replicable in a lab. The main characteristic of the chosen WCCR could be that it contributes to avoidable food waste. Ideally, more than one food commodity with WCCR should be found among a population, which would help to ensure the calculation of a more reliable UR. We recommend choosing food commodities that are not too culturally potent. BW values in the present study were too low, which made data analysis challenging. The low values might be due to the fact that according to many Iranian people's beliefs, bread is considered sacred in their culture, and wasting it is stigmatized [40]. Moreover, consumers' perception of edible and inedible food, and thus of avoidable and unavoidable waste, might vary among different populations with different cultural, ethnic, or religious backgrounds [2,37,60]. For example, while potato peel might be considered as inedible and hence unavoidable waste in some cultures [61], others find it nutritious [62]. Therefore, it is essential that the researchers familiarize themselves with the cultural context of their target population.
2. Household survey: After identifying the food commodities with WCCRs, a survey must be carried out to evaluate the household food waste using the self-assessment methods (diary or recall questionnaires). However, additional questions on the CRs of the food commodities identified in Step 1 are necessary to enable calculation of the waste amount for the identified food items in the households that implement the WCCRs, for example, "do you discard the inner crumb of baguette?".

3. Food waste measurement in lab: The third step is to randomly acquire samples of the food commodity identified in Step 1 and perform the WCCR. The replication of WCCR in the lab should be carried out by an untrained panel to reduce bias. Subtracting the mass of each food sample before WCCR execution from its mass after WCCR execution reveals the waste amount.

4. Calculating the UR: In this step the surveyed households are grouped based on their CRs for the food commodity identified in Step 1. The mean waste is calculated separately for the group with WCCR being the typical consumption habit. The underestimation factor can be calculated based on the following equation.

$$\text{UR} = \frac{\text{The waste amount measured in the lab}}{\text{The waste amount obtained from the survey}}$$

If more than one food commodity is identified in Step 1, an average UR could be calculated for all of them.

5. Self-assessment survey underestimation correction: Finally, making use of the calculated UR, the survey waste results for all food items are inflated in order to correct the underestimation caused by respondents' underreporting.

Study Limitations and Future Research Directions

A major drawback of the work was that the panel was chosen outside of the survey target population due to the research limitations. Therefore, finding correlations and regressing the results of the survey and the lab measurement was not possible. On the other hand, having paired data, as Elimelech et al. [24] had, allows the researcher to conduct more critical analysis and hence gain more accurate results. Therefore, random selection of panelists among the surveyed population can be recommended.

In general, complementing the self-assessment approach with objective methods, such as the one used in this study or direct measurement methods implemented by other researchers [24,26], does not suffice to improve the results. The adoption of food waste questionnaires in accordance with the context of the study is also necessary. One idea could be establishing locally standardized portions sizes for different types of food to facilitate responding to and analyzing questions. Referring back to nutritional science, locally validated dietary intake assessment questionnaires such as food frequency questionnaire (FFQ) provide the interviewees with multiple-choice options to select the portion size that is closer to the estimated intake of particular food items (e.g., one palm for flatbread or a matchbox for fresh cheese) [63]. This method has been well-established over time and yields acceptable data. A similar approach can be found in food waste valuation studies such as the European project REFRESH [21], in which particular portion sizes are defined for each food group. However, the portion sizes seem to be too generic (e.g., only using a serving spoon of potato or a slice of bread), and this may not be applicable in many geographical and cultural contexts, especially in developing countries.

Another suggestion for improving the reliability of food waste data could be clarifying the definitions of avoidable and unavoidable food waste [64] not only for the study objectives, but also for the survey participants. While conducting any types of self-assessment methods, whether it is a food waste diary or questionnaire survey, it is necessary to reach a mutual understanding with the respondents regarding what is considered as waste. Misunderstanding the food waste definition might result in high variance and low reliability of data.

5. Conclusion

In conclusion, this paper proposes the augmentation of self-assessment food waste surveys with lab measurements to obtain more reliable data on households' food waste. Even though the direct measurement might yield more accurate results, the hybrid approach of self-assessment survey and lab measurement could achieve a compromise between accuracy and feasibility. In general, although the present paper's BW results may be limited to specific geographical and cultural conditions, the methodological approach of this study could be applicable in a variety of research settings. It is likely to find specific CRs in different cultures, which may cause the wastage of certain food commodities. This will allow the researchers to replicate the CRs, and precisely measure the causing waste amount, which can be used to correct the underestimation in the results gained through self-assessment methods. This approach could facilitate the attainment of an acceptable sample size while adjusting the self-assessment method underestimation using the UR calculated based on lab measurement. Thus, adjustment could lead to a deeper understanding of the actual situation with regard to food waste. The proposed hybrid approach could be convenient for implementation in developing countries where research resources are particularly scarce. The outcome of the present paper could contribute to filling the household food waste data gap, which might be one major barrier in the obtainment of effective strategies to achieve sustainable and responsible consumption patterns. However, it is vital to test this approach in different settings and validate the methodology before implementing it in large-scale studies. Further research is needed to examine the possible ways to identify food commodities with WCCRs.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the Shiraz University of Medical Sciences on September 30, 2018, with the code IR.SUMS.REC1397.595.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Chapter 5: Article 4

Title of the Article: Household Food Waste Quantification and Cross-Examining the Official Figures: A Study on Household Wheat Bread Waste in Shiraz, Iran

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Abstract

The global consumer food waste (FW) estimates are mainly based on modeling data obtained from governments. However, a major data gap exists in FW at the household level, especially in developing countries. Meanwhile, the reliability of the existing data is questionable. This study aimed to quantify wheat bread waste (HBW) in Shiraz, Iran, and cross-examine the governmental HBW data. Face-to-face waste recall questionnaire interviews were conducted in 419 households from December 2018 to August 2019. A multistage sampling strategy consisting of stratification, clustering, and systematic sampling was employed. Moreover, we carried out a comprehensive document review to extract and analyze the official HBW data. The results revealed that the HBW in Shiraz is 1.80%—the waste amounts for traditional bread and non-traditional bread were 1.70% and 2.50%, respectively. The survey results were compared with the previous official data, revealing a substantial contradiction with the 30% HBW reported between 1991 and 2015. Possible reasons for this disparity are explored in this paper. Although our results cannot be generalized to other food commodities and locations, our findings suggest that considering the substantial likelihood of bias in the official data, policymakers should conduct more FW measurements and re-evaluate the accuracy of the existing data.

Keywords: food loss and waste; food waste accounting and data; food waste index; sustainability; sustainable production and consumption; food waste quantification; global data

1. Introduction

Despite the tremendous planning and efforts to ensure global food and nutrition security, the food production and consumption system appears to be inefficient and unsustainable. The members of the United Nations (UN) have agreed to end hunger while preserving the environment by 2030 through sustainable development goals (SDG) number 2 (zero hunger) and 12 (responsible consumption and production) [1]. Based on this rationale, avoiding or reducing food loss and waste (FLW) is prudent to increase food security while reducing the environmental and economic burdens. The third target of SDG 12 is explicitly focused on the reduction of FLW [1].

In order to plan the most effective courses of action toward achieving the UN's FLW reduction target, gaining a realistic and accurate understanding of the status quo in the agri-food system plays a vital role. Furthermore, accessing robust and accurate data is the key to monitoring and assessing whether an FLW reduction plan achieves its objectives [2]. Two UN-affiliated organizations—i.e., the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP)—are responsible for monitoring SDG 12.3 and providing information and guidance for the decision makers to develop FLW reduction policies [2].

It is important to distinguish food waste from food loss, as their stages of occurrence and quantification methods are fundamentally different. According to the FAO's definition, food loss refers to the reduction in the amount of food along the production and supply chains from farm to, but not including, retail, whereas food waste is the discarding of food at the consumption stage [3]. The consumption stage includes retail, foodservice, and households [4]. The terms "food loss" and "food waste" are hereafter used according to the definitions mentioned. Currently, the FAO is focused on food loss, and the UNEP is the custodian for food waste [2].

In 2011, when the FAO was solely responsible for both food loss and food waste, the first systematic analysis of global FLW showed that about one third of the total food produced is lost or wasted throughout the food supply chain (FSC) [5]. The FAO's 2019 report on FLW indicated the food loss to be 14% [2], and, in 2021, the UNEP estimated that 17% of globally produced food is wasted [4]. These figures add up to 31% of FLW, which strongly agrees with the FAO's 2011 report. This means that the FLW reduction plans have not been proceeding in the UN's desired direction since 2011.

However, according to the FAO's 2011 report [2], the lack of data on the extent and locations of FLW occurrence is substantial. Between 1990 and 2017, the FAO received FLW data annually from only 39 countries [2]. Therefore, the question arises as to what extent the recent estimations made by the FAO and UNEP reflect the actual amount of FLW, as their findings rely heavily on estimations and exploitation of the limited data available. Therefore, it is crucial to clarify how these organizations currently gather FLW data.

The FAO has extensively conducted studies on food loss in different countries during the last few years. Examples may include but are not limited to the analysis of cassava loss in the Republic of Guyana [6], studies on maize and rice losses in the Democratic Republic of Congo [7], case studies on postharvest loss of chickpea, mango, and rice in India [8], and groundnut and maize loss analyses in Malawi [9]. However, the origins of most of the FAO's food loss statistics are still governments and official local sources [3]. At the same time, the UNEP receives food waste data almost entirely from local governments [4] and, to the best of our knowledge, has no ongoing study on food waste. Therefore, the food waste estimates mainly rely on proxy data, resulting in a more substantial data gap in food waste compared to food loss [4,10].

Presumably, quantifying food waste seems more challenging compared to food loss. The argument would seem to be that analyzing the mass flow along FSCs to evaluate food loss may seem relatively straightforward, although it entails transparency. Notably, countries with advanced infrastructure keep precise records of food products throughout their FSCs—e.g., the European Union (EU) countries [11]—and can better estimate food loss. On the other hand, evaluating food waste may seem more challenging because monitoring the material flow at the consumption stages is complicated, especially household food waste (HHFW), which accounts for 61% of the total food waste at the consumption stage [4]. Generally, in most countries, a form of food inventory management is expected to exist in the retail and foodservice sectors, which may facilitate measuring food waste using various methods, such as mass balance, volumetric assessment, and counting/scanning [4]. However, the multifaceted nature of the HHFW complicates its quantification.

The UNEP implements a three-level methodology—i.e., level 1: modeling the available data; and levels 2 and 3: food waste measurement and providing additional information [4]. Currently, the UNEP estimates are mainly based on modeling data, and measurements are the future plans. The UNEP analyzed the food waste data from 59 countries, only 17 of which used standard food waste quantification methods, yielding "high-quality data compatible with SDG 12.3" [4] (p. 9). In the case of the other 42 countries, where there is a lack of robust data, the UNEP approximately estimated food waste by using the modeling approach to extrapolate the data provided by other countries [4]. In particular, a substantial data gap exists at the household level [4]. Given that the UNEP's success in providing proper guidance toward SDG 12.3 depends on achieving a precise estimation of HHFW, the importance of evaluating the accuracy of the data provided by local governments and identifying the main data gaps cannot be emphasized enough.

During the last decade, many studies focused on HHFW quantification. However, according to Xue et al.'s [10] systematic review, the majority of these studies were carried out in developed countries, leaving a data gap in developing countries. A similar conclusion can be drawn from the UNEP's 2021 report [4]. According to the UNEP, only 14 countries—all developed countries except Ghana—have high confidence data on HHFW. Distinctively, the Near East and North Africa (NENA) region countries lack reliable data on HHFW [4,12,13].

The NENA region imports over half of its food and still struggles to meet the demand while its level of FLW is estimated to be above the global average—annually 250 kg per person [14]. In many NENA countries, food is mainly lost at the production and postharvest stages, basically due to poor technological infrastructure [14]. However, a substantial share (32%) of the FLW still occurs at the consumption stage [15]. The rich NENA countries, such as the Kingdom of Saudi Arabia (KSA), waste even more food at the consumption stages, mainly due to their extravagant lifestyles and cheap food [16]. Based on the 2021 report of the Food Sustainability Index [17], the food waste amounts in KSA and the United Arab Emirates (UAE) are estimated to be 151 and 134 kg per person per annum, respectively.

However, despite the high level of food waste, after Sub-Saharan Africa, NENA has the lowest policy response to food waste [17]. A major factor hindering the food waste reduction plans in most NENA countries is known to be the lack of reliable data [14]. A systematic review from 2020 [18] accentuated the scarcity of FW data in some of the Arab states of the Persian Gulf. The UNEP has classified the confidence level of the different countries' HHFW estimates into "high confidence", "medium confidence", "low confidence", and "very low confidence" [4] (p. 12). Among the NENA countries, only KSA has "high confidence" data, and Bahrain, Iraq, and Lebanon have "medium confidence" data [4] (p. 65). The HHFW data of Jordan, Kuwait, Mauritania, Oman, Palestine, Qatar, Syria, and UAE are classified as "low confidence" [4] (p. 65). All other north African countries, along with Yemen and Iran, have "very low confidence" HHFW estimates [4] (p. 65).

As a major country in NENA, Iran faces tremendous challenges in quantifying and reducing its food waste. Over the last decade, Iran's economy has been shrinking drastically due to international sanctions. Between 2011 and 2015, the country's crude oil exports almost halved [19]. The U.S. "maximum pressure" policy cut Iran's access to international financial services [19]. Hence, Iran has been overusing its natural resources to overcome international sanctions and reach self-efficiency [20,21]. On the other hand, Iran's young and dynamic population seems to be transitioning toward a modern and extravagant lifestyle with a tendency toward consumerism, resulting in increasing food waste [5]. Based on the UNEP data, HHFW in Iran is around 5.9 million tons per annum but, as mentioned earlier, with very low estimation confidence [4]. Studies on HHFW in Iran were mainly focused on food waste attributions rather than its amount [22–24]. Therefore, information on the quantity of HHFW in Iran is scarce.

The present study aimed to quantify HHFW in Iran and critically examine the accuracy of governments' HHFW statistics by comparing them with our primary data. Due to limited research capacities, investigating all food commodities was not possible. Therefore, wheat bread (hereafter referred to as bread) was chosen as the focus of the study due to its importance as the primary staple and most consumed food commodity in many developing countries, especially in the NENA region [25].

NENA countries are among the biggest wheat importers globally, with around 36 million tons of wheat per annum [14]. Bread is considered to be of utmost importance to Iran's economy and is the most popular food commodity in the country [26,27]. Iran is among the biggest wheat producers worldwide. The FAO's latest official data demonstrate that Iran produced more than 13 million tons of wheat in 2018, ranking 15th globally [28]. No recent study can be found reporting the Iranians' bread consumption amount. However, the last and most commonly cited national investigation, which was based on the data from 2000 to 2002, indicated that the average daily bread intake in Iran was 320 gr per capita [29]. Jafari et al. [30] assumed that Iran's bread consumption should be similar to that of Turkey—supposedly due to cultural and geographical similarities—and, therefore, one of the highest in the world. A 2012 study on 22 European countries, the United Kingdom, and Turkey revealed that Turkey's average per capita bread consumption is 411 gr per day—more than 2.5 times higher than the average of the European countries [31].

To achieve the aim of this study, a survey was conducted to quantify household wheat bread waste (HBW) in Iran. The study location was chosen to be Shiraz—home to about 1.6 million inhabitants [32] and the capital of Iran's major wheat-producing province, Fars. Among 31 provinces, Fars produces almost 10% of the country's wheat—about 1.2 million tons per year [33]. Because official statistics on HBW were not easily accessible, we carried out a thorough document review to gather, analyze, and summarize the previous reports on HBW in Iran.

2. Materials and Methods

2.1. Study Design and Sampling

The present study was carried out from December 2018 to August 2019 in Shiraz, Iran. A door-to-door self-assessment recall questionnaire survey was conducted to quantify the HBW and gather other relevant data. A total of 419 households were surveyed. In this study, a 'household' was defined as two or more persons living in one house and sharing food and the costs for food. One person per household, identified as the member responsible for food preparation and nutrition, was interviewed. The study was performed in line with the Declaration of Helsinki, and the study protocol was approved by the Ethical Committee of the Shiraz University of Medical Sciences, with the code IR.SUMS.REC.1397.595. All interviewees were assured about the anonymity and confidentiality of their responses and provided written consent for inclusion prior to the onset.

The sample size was computed as described below based on Daniel's equation [34], which is commonly used in population studies. We chose this equation to obtain adequate observations for statistical inference while controlling the survey's executive costs. Finally, a 10% buffer was added to the computed sample size to account for possible data loss.

$$\mathrm{n} = \frac{NZ^2P(1-P)}{(N-1)E^2 + Z^2P(1-P)} = 384$$

where n identifies the sample size;

N is the population (households in Shiraz = 477,916 [32]);

Z denotes the Z score based on the level of confidence (for a level of confidence of 95%, Z = 1.96);

P stands for the expected prevalence or proportion (assumed to be 50%);

E is an abbreviation for the margin of error (assumed to be 5%).

Final sample size = n + ~10% = 419

A three-layer sampling strategy was implemented to ensure homogeneity in the geographical distribution of the selected samples. In the first instance, stratified sampling was used. Each of the ten municipal districts of Shiraz was defined as one stratum. The number of samples within each stratum was determined using the population weight of each district based on the number of households living there. The latest available national census data were used for reference [32]. In the second instance, cluster sampling was applied. Each district (stratum) was divided into congruent square blocks using the fishnet tool in ArcMap 10.4.1 [35]. A shapefile population map—provided by the city hall of Shiraz—was used to identify the residential blocks. The clusters were randomly selected from the residential blocks within each stratum. The number of clusters was calculated as 10% of each stratum's sample size. Finally, the target households were selected systematically. Every third house was selected, starting with the house located at the southwest endpoint of the map and spirally approaching the other houses clockwise toward the center of the block until ten households within each cluster were successfully interviewed. If a household was unavailable, the fifth household forward, then backward, was approached. If none of them were available, they were skipped, and the subsequent third household was approached.

2.2. Questionnaire Structure and HBW Measurement

A researcher-made questionnaire was used to gather data. The questionnaire had three sections: demographics and socioeconomic data, bread waste, and bread storage condition and duration. The first section consisted of questions on the interviewee's age, gender, and education level and the occupation of the head of the household. In the second section, questions on the amount of bread purchased and wasted were asked for different types of bread. The last section involved questions about the condition and duration of bread storage in households.

The focus of this study was on ten commonly consumed wheat bread types that were chosen based on the Iranian National Standardization Organization (INSO) [36,37]. The bread types were categorized into traditional bread (TB) and non-traditional bread (NTB). Table 1 presents the bread types' names and descriptions. Hamburger bread is hereafter referred to as bun. Detailed characteristics and specifications of these bread types are provided in INSO [36,37] and Karizaki [26].

Table 1. The description of the studied bread types based on their categories and characteristics.

Bread Category	Bread Type	Description		
		Geometric Shape	Bread Kind	Texture
Traditional	Lavash	Rectangle, pseudo-ellipse	Non-sweet, flat	Soft, crispy
	Sangak	Pseudo-triangle	Non-sweet, semi-raised	Crispy
	Taftoon	Circle	Non-sweet, flat	Crispy
	Traditional babari	Pseudo-ellipse	Non-sweet, semi-raised	Crispy, soft
Non-traditional	Baguette	Pseudo-ellipse	Non-sweet, raised	Crispy
	Hamburger (bun)	Circle	Non-sweet, raised	Doughy
	Sandwich	Pseudo-ellipse	Non-sweet, raised	Soft, doughy
	Broetchen	Pseudo-ellipse	Non-sweet, raised	Doughy
	Toast	Rectangle, square	Non-sweet, semi-raised	Soft
	Non-traditional barbari	Pseudo-ellipse	Non-sweet, raised	Soft

Source: Adopted from Karizaki's [26] and the Iranian National Standardization Organization [36,37].

The interviewees were asked to provide an estimation of the number of bread pieces bought in a typical grocery purchase and an estimation of the amount of waste from the same specific purchase. Corrado and Ardente's [38] (p. 849) definition of "avoidable food waste" was referenced to identify HBW, which refers to the disposed of edible parts of bread not used for other beneficial purposes. These questions were separately repeated for each bread type. In the questionnaire, the HBW amount was stated using the guideline for standard domestic food portion sizes—i.e., one hand palm for a flatbread; a 7 cm cut for a baguette, sandwich, or broetchen; a half of a piece for a bun; and a slice for toast bread [39]. The same guideline was used to convert the wasted portions to grams. A nutritionist calculated the mass using dietary assessment exchange lists if the interviewee's answer was not expressed using the standard portion sizes. Responses that were too subjective were excluded from the dataset. The mass amount of purchased bread pieces was calculated in grams according to Ghafarpour's [39] guideline. The waste amount was calculated as the ratio of HBW mass to purchased bread mass, expressed as a percentage. The total HBW was calculated as the mean of all bread types' waste, as TB and NTB waste were the means of the traditional and non-traditional bread types, respectively.

Questions regarding storage methods and duration were asked regardless of the bread type. The interviewees were asked a multiple-choice question about whether they store bread in a freezer, a refrigerator, or at room temperature. The answers to the storage duration question were grouped into 'up to 2 days', '3–4 days', '5–7 days', and 'more than a week'.

2.3. Statistical Analysis

The statistical analyses were performed using IBM SPSS Statistics version 25 [40] and R version 3.6.2. [41] with a significance level of $p < 0.05$. Paired samples and independent samples T-tests were performed to identify significant differences across the bread categories. The linear regression model and ANOVA were used to determine whether the storage method, storage duration, or their interaction significantly affected the HBW amount. The amounts of HBW in the different storage methods and duration groups were compared using a pairwise Bonferroni post hoc test.

2.4. Document Review

A comprehensive internet search was carried out to find publications and reports focused on HBW in Iran. The keywords 'household bread waste' in Persian and English were used to search within governmental, organizational, and academic reports as well as peer-reviewed articles and conference proceeding papers, without publication date limitation. The transcripts were analyzed to gather information on their bread waste results and methodological approaches.

3. Results

3.1. Overview of the Surveyed Households

A total of 1548 individuals lived in the 419 surveyed households, with an average household size of 3.69 (SD = 1.22). Table 2 provides a summary of the demographic and socioeconomic descriptions of the surveyed households. It is apparent that the majority of respondents were female, and it is also indicated that females were predominantly responsible for food preparation in the households. On the other hand, most of the studied households were male-headed. Moreover, Table 2 provides information on the education level and occupation of the heads of the households.

Table 2. Demographic and socioeconomic summary of the studied households.

Variables		N	% of Total N	Mean	(SD)
Gender [1]	Female	399	95.20	48.23	(13.41)
	Male	20	4.80	48.20	(20.52)
Head of the household	Female	39	9.31	54.74	(15.03)
	Male	380	90.69	47.56	(13.51)
Education [2]	Illiterate and primary	94	22.40	53.64	(13.86)
	High school and diploma	229	54.70	46.75	(12.68)
	University degree	96	22.90	46.46	(15.03)
Occupation [2]	Unemployed	49	11.70	55.24	(14.38)
	Skilled worker	105	25.10	43.03	(12.15)
	Employee	116	27.70	42.29	(12.87)
	Professional	23	5.50	42.30	(11.49)
	Retired	126	30.10	56.37	(10.51)
Total		419	100.00	48.23	(13.8)

N = Number of observations; SD = Standard deviation; [1] Variable belonging to the respondent; [2] Variables belonging to the head of household.

3.2. Bread Waste

Out of 419 surveyed households, three respondents did not answer the bread wasting and purchasing questions (0.72% missing). Table 3 shows the mean HBW percentage presented for the different bread types and categories. The NTB waste numerical value was almost 1.5 times higher than TB waste. A paired sample T-test did not find any significant difference between the two categories. However, as not all households were NTB consumers, the paired comparison excluded around 27% of the TB waste observations. Therefore, an independent samples T-test was carried out, which revealed that the difference between TB and NTB waste was significant (α = 0.016). Lavash and baguette had the highest waste in their bread categories.

The number of observations in Table 3 also indicates how many households consumed each bread type. The bread with the highest consumption was Sangak, while Taftoon was the least consumed. A total of 210 of the interviewees (50.48%) claimed that they do not waste bread at all in their households. Out of 416 TB-consuming households, 237 (56.97%) reported being zero-wasters, while 201 out of 304 NTB-consuming households (66.12%) were zero-wasters. The mean percentages are presented, taking the zero-waste values into account.

Table 3. The presentation of bread waste percentages based on bread types and categories.

Bread Types and Categories	N	Waste Mean Value (%)	SD
Lavash	335	1.96	5.31
Sangak	399	1.89	4.74
Taftoon	47	1.37	2.83
Traditional babari	197	1.57	5.05
Traditional bread	416	1.70	3.70
Baguette	149	3.58	6.72
Hamburger	136	2.54	5.25
Sandwich	229	2.97	7.04
Broetchen	86	3.43	8.46
Toast	132	3.46	10.31
Non-traditional barbari	54	1.00	3.50
Non-traditional bread	304	2.50	5.26
Total	416	1.80	3.36

N = Number of observations; SD = Standard deviation.

3.3. Storage Method and Duration

As Figure 1 shows, almost two thirds of the study population reported that they store bread in freezers, while about one fourth use refrigerators. Storing bread at room temperature was found to be the least common way of storing bread in the surveyed households.

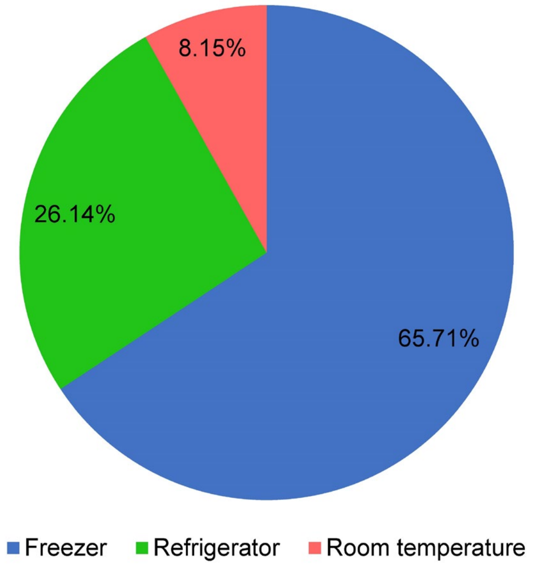

Figure 1. The frequency of different bread storage methods among the surveyed households.

Figure 2 indicates that almost a third of the respondents stated that, in their households, bread is normally kept up to two days after purchase. Less than a third of the study population stated their bread storage duration is about 3–4 days, followed by the group who reported storing bread for 5–7 days after purchase. A minority reported that they store bread for more than a week.

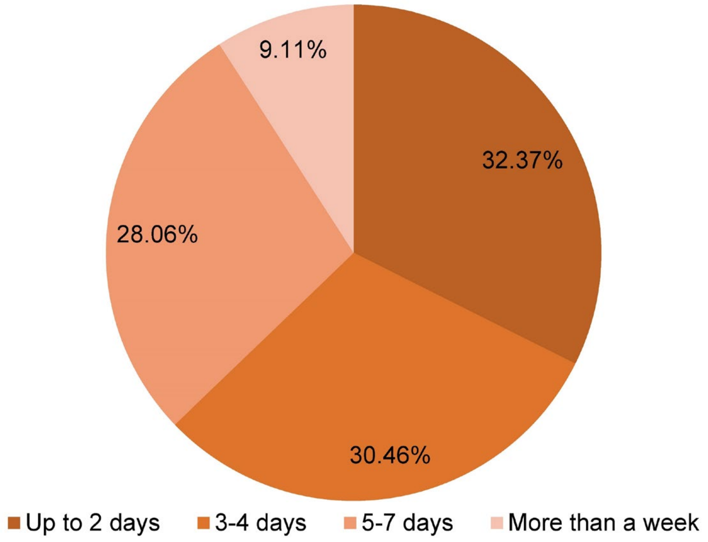

Figure 2. The presentation of different bread storage duration groups.

Linear regression models revealed that the storage method had a significant effect on the total HBW (α = 0.026) and TB waste (α = 0.000) and that storage duration and its interaction with storage method did not affect total HBW. Neither storage method nor duration caused any significant variation in NTB waste data.

Table 4 compares the mean waste percentages of the bread categories, which are presented based on the storage methods. The pairwise Bonferroni post hoc test revealed that for the total and TB waste there is a significant decrease in wastage when bread is stored in freezers and refrigerators compared to storage at room temperature. The NTB waste mean values did not significantly differ among the storage method groups.

Table 4. Mean waste percentages of different bread categories based on storage method.

Storage Method	Freezer	Refrigerator	Room Temperature
Total waste	1.62 [a]	1.81 [a]	3.43 [b]
N	273	109	32
Traditional bread waste	1.31 [a]	1.91 [a]	4.36 [b]
N	273	109	32
Non-traditional bread waste	2.43	2.51	2.52
N	197	78	28

N = Number of observations. Note: The values with different superscript letters in a row are sig-nificantly different ($p < 0.05$). The group sizes are unequal. The harmonic mean of the group sizes is used.

3.4. Previous Publications about HBW in Iran

The document review identified seven publications and reports focused on HBW in Iran. Table 5 lists these documents and summarizes their findings and methodologies. These documents were published between 1991 and 2015. The oldest publication was a national research project report by Mirfakhrayi [42] investigating bread waste in households and bakeries in Tehran, Iran, by employing a direct measurement method. Similar research was conducted in 2015 by Irani et al. [43], who also used direct measurement to assess HBW in the provinces of Tehran, Khuzestan, and Golestan. Moreover, the Iranian parliament published two reports on HBW in 2012 and 2015. Only one peer-reviewed article [44] focused on HBW in Iran. The two other publications were presented at national conferences [45,46]. As can be seen, only Irani et al. [43] stated that HBW in Iran ranges between 12 and 16%, while others claimed that HBW in Iran is around 30%. Among all reports, only two were published based on primary data collection.

Table 5. The list and description of publications about household bread waste in Iran.

Publication Year	Author(s)	Stated BW	Method/Reference	Publication Type
1991	Mirfakhrayi et al.	33.5%	Direct measurement at HH level	Research project report
1994	Mojarad	30%	Not given	Conference paper
2005	Irani et al.	12–16%	Direct measurement at HH level	Research project report
2007	Omidvar et al.	30%	Mirfakhrayi et al. [42]	Peer-reviewed article
2012	Baradaran Nasiri et al.	33.1%	Mirfakhrayi et al. [42]	Parliament report
2015	Talebi	20–40%	Not given	Parliament report
2015	Rastegary	30%	News agencies	Conference paper

BW = Bread waste; HH = Household.

4. Discussion

This study revealed that almost all of the study population consume at least one type of TB, and almost 75% purchase one or more type of NTB. This privileged the study by enabling the participants to easily relate to the HBW questions. The results showed that the mean waste of all bread types in Shiraz was 1.80%, ranging from 1.00–3.58%, depending on the bread type. Based on the documents we found, both the TB and NTB waste figures in our study were substantially lower than the 30% that is widely regarded as the amount of HBW in Iran [42,44–48]. However, the reference or the methodology for some of these reports seem ambiguous or, in a few cases, not even accessible, and actual field studies to quantify HBW in Iran are scarce. Among the authors who claimed that the HBW is around 30%, only Mirfakhrayi et al. [42] carried out a primary data collection using the direct measurement method. However, this study took place 30 years ago and may, therefore, no longer be applicable. Between the two reports by the Iranian parliament in 2012 and 2015, the first one cited Mirfakhrayi et al. [42], and the latter did not mention any reference. From the other three publications, Omidvar et al. [44] cited Mirfakhrayi et al. [42], Mojarad [46] did not provide any supporting evidence, and Rastegary [45] referred to five reports and interviews with officials that were published by news agencies [49–54]. Of those five news releases, one was unavailable on the internet [51]. After factual analysis, we concluded that the accuracy of the officials' statements in the other four news releases is doubtful. Presumably, those officials referred to the 2012 Parliament report, which cited Mirfakhrayi et al.'s 1991 study that is arguably outdated. Shahedi [55] critically questioned the 30–35% HBW values reported by the officials and conjectured that a more precise estimate at the consumption level in Iran should be around 20% HBW.

The most recent and the only other primary data collection that we found was carried out by Irani et al. [43], who found the HBW to be 12–16% using direct measurement. Although our findings are in better agreement with Irani et al. [43], the difference is still inordinate. The following explanations could be argued to justify or elucidate why our HBW results were so much lower than the former findings. We oriented our focus mainly on the two studies by Mirfakhrayi et al. [42] and Irani et al. [43], who carried out primary data collection.

The inconsistency in food waste definition could be one reason for the difference between our findings and the previous reports on HBW in Iran. Neither of the two studies that carried out primary data collection for HBW assessment in Iran [42,43] provided a clear definition for HHFW in their papers. As stated in Section 2, the definition provided by Corrado and Ardente [38] was used in this study, which excludes portions of edible material used for other beneficiary purposes—e.g., cooking, feeding domestic animals, and compost. In other words, if the household used not-eaten food for other purposes, that amount did not count as waste. Therefore, since it is unclear whether Mirfakhrayi et al. [42] and Irani et al. [43] included the not-eaten portions of food used otherwise in their waste calculations, it is difficult to compare their results with ours. The contrast in HHFW definitions in various studies has been a crucial obstacle in comparing data across studies [56]. Nonetheless, the dichotomy between our findings and the previous ones remains considerable.

Another reason for the deviation of our findings from previous ones could be sought in the nature of the method used in this study to assess HBW, which was HHFW self-assessment by means of recall questionnaire. There is ample evidence suggesting that self-assessment methods for estimating HHFW—including recall questionnaires—underestimate the waste amount [10,57–59]. The majority of respondents claimed that no bread wastage occurs in their households. More than half of the TB consumers reported that they do not waste TB, while two-thirds of the NTB consumers reported zero waste for that bread category. Our observation bears a close resemblance to Djekic et al.'s [60] study on HHFW in Serbia in which a high number of respondents were zero wasters, ranging from 37.2% of the respondents for bread and bakery products to 78.1% for processed fruits. However, responses to recall questions may contradict the truth, as in self-assessment the participants may understate the food waste amount because they might not recall the precise amount or even the occurrence of wastage [61]. Some participants' dishonesty in answering the questions or their embarrassment in admitting to food wastage could also cause an underestimation of food waste [62]. Therefore, it seems safe to assume that our waste results were lower than the actual amounts in the studied households, partly due to the employed methodology.

The underestimation ratio (UR) for HBW assessment of the same study population was calculated to be 1.80, 1.24, 1.58, and 1.46 for sangak, baguette, bun, and sandwich bread, respectively [63]. The UR is the ratio of the more accurately estimated waste results to the outcome of the self-assessment questionnaire. The accurate HBW values in Ghaziani et al.'s [63] work were calculated by measuring HBW at a lab after replicating the waste-causing consumption recipes. In order to correct the underestimation bias in our data, the sangak UR can be used for the TB waste values, and the average of the other three URs can be used for the NTB. As a result, TB waste would turn out to be 3.06%, and NTB waste would become 3.58%. These figures would likely reflect a more accurate estimation of HBW in the surveyed households. Nonetheless, the outcome would still be substantially lower compared to previous findings.

Another possible explanation for achieving different outcomes may be the change in bread storage method over time. The analysis of our data showed that storing at room temperature causes more waste as opposed to storing in freezers or refrigerators. Nevertheless, no association was observed between the storage method and NTB waste. However, based on our anecdotal observations, the surveyed households mostly stored TB for longer and consumed NTB fresh. As the question regarding storage method was asked regardless of the consumed bread type, it could be assumed that the respondents were referring to the TB storing method while answering the question. Given that assumption, it is reasonable to conclude that the storage method does not affect NTB waste. However, the storage method effect on total HBW and TB waste remains relevant. Mirfakhrayi et al. [42] stated that, among their study population, 9.6% used freezers, and 42.3% used refrigerators for bread storage, while almost half of the participants reported that they keep bread at room temperature. Contradictorily, a small minority of our interviewees indicated they store bread at room temperature, and more than 90% used either freezers or refrigerators. This change could be associated with the positive trend in Iranians' access to modern appliances such as freezers and refrigerators over the last few decades [64]. Unfortunately, Irani et al. [43] did not include the storage method in their research; therefore, we could not obtain information to enable the comparison of bread domestic storage methods between Mirfakhrayi et al.'s [42] work and ours.

In addition, the storage duration effect was investigated in the present study. However, the data analysis did not reveal any significant impact in that respect. Despite the possible assumption that due to a higher storage length a higher bread wastage occurs, duration alone is not responsible for bread decay and wastage, and the more determining factor is the storage method. For example, bread can be stored for a long period in a freezer without causing additional waste. Therefore, solely analyzing the effect of bread storage duration on HBW is irrelevant, while further investigations on the interaction effect of storage method and duration are required. Such an interaction effect was not found in our dataset, possibly resulting from the small sample sizes in the data subgroups.

Furthermore, the relatively low HBW in this study could be attributed to the economic recession and the spike in bread prices shortly before and during our survey. Concurrent with our study, Iran was suffering from an unprecedented economic crisis. Iran's economy faced enormous shocks and turbulences during the 2016 US presidential election, after Donald Trump's victory in the election, and after his withdrawal from the Joint Comprehensive Plan of Action (JCPOA) [65]. The Trump administration started imposing new sanctions on Iran in July 2017, followed by other sanctions and opposing measures, with the climax being America's withdrawal from the JCPOA in September 2018 [66]. The aftermath soon evolved into drastic impacts on Iranians' livelihood. The annual growth in the consumer price index ranged between 6.4% and 18.2% from 2012–2017. This index raised to 29.1% and 47.8% in 2018 and 2019, respectively [67]. The point-to-point inflation rate was almost doubled in October 2018 (18.4%) compared to 9.9% in the previous year [68]. The Iranian currency value fell drastically [69], and the country's oil export decreased continuously during Trump's presidency [70]. Consequently, the price of a vast majority of commodities, including food, rose dramatically.

The pace of price growth for food commodities, including bread, came to a tremendous high point in December 2018, coinciding with the start of our survey. According to a report published by the Central Bank of the Islamic Republic of Iran [68], in November 2018, the food consumer price index witnessed a 59.9% increase, with the bread index rising 31.3% compared to the similar month of the previous year. For food and bread indices, these numbers were 14% and 10.9% in November 2017, respectively, [71]. The same report indicates a sharp surge in the slope of the consumer price index changing trend, particularly for the food group index, occurring around the middle of 2017, testifying to the drastic impact of the sanctions and political complications on food prices. During this period, the income of Iranian urban households increased by only 18.6% in 2018 [72] and 24.4% in 2019 compared to the corresponding preceding year [67].

As a result, Iranian consumers' purchasing power decreased enormously in 2018 and 2019 [73]. Several studies have shown that higher food prices could lead to less food waste [74–77]. This correlation may well be a consequence of consumers avoiding over-purchasing when food prices rise [74,75]. A lower purchasing power may encourage consumers to adopt a more frugal lifestyle and motivate them to avoid food waste to reduce monetary loss [78,79]. Therefore, the Iranian consumers may have chosen a more conservative approach to food purchasing while trying to utilize their resources with caution, which leads to lower HHFW—including HBW.

The bread quality improvement during the last decade in Iran could also be deemed an influential factor in HBW reduction. A national policy that came into effect in 2010 focused on improving the quality of bread production and consumption [80]. Since 2013, the Iranian Ministry of Health and Medical Education has allocated an expert working group to promote the nutritional quality of bread [81]. The evidence suggests that low food quality could be one of the drivers of wasting food at the consumption stage [82–84]. Therefore, there is a logical relationship between the recent bread quality improvement and the limited HBW found in this study.

Culturally speaking, bread is highly revered among Iranians. Many Iranians refer to bread as “God’s blessing,” and they consider it “holy” [26]. Therefore, wasting bread is stigmatized among Iranian consumers, and it would be rational to assume that bread waste in Iranian households is limited. Other studies may be found that indicate a relatively low amount of loss or waste for other commodities. For example, Tostivint et al. [85] estimated a 1.4% loss throughout Pakistan’s dairy supply chain stages, including suppliers, collection points, dairy factories, and distribution and retail. In another study, Silvennoinen et al. [86] (p. 1061) reported that most of the participants in the Finnish households “produced little food waste”—less than 1 kg of food waste within two weeks. Nonetheless, they could not provide a percentage of total purchased food waste, as this related question was not asked. In general, consumers feel responsible for food consumption and show ethical and social concerns about food wastage [87,88]. In particular, the NENA countries that are known to have predominantly Muslim populations are expected to avoid wasting food, as it contradicts the teachings of Islam [16]. Nonetheless, HHFW remains a major issue in that region. This issue cannot be effectively addressed unless an accurate estimation and evaluation of the level, reasons, and hotspots of food wastage are obtained.

Overall, our findings confirm the UNEP’s [4] very low confidence in Iran’s HHFW official statistics. Nonetheless, HBW in Iran may not be the only example of contradictory information. The UNEP recognizes the confidence level of most NENA countries’ HHFW data to be either low or very low [4]. However, the ambiguity about HHFW statistics is not limited to NENA or even developing countries. As explained in Section 1, only 39 countries continuously reported on FLW to the FAO [2], and the UNEP recognized the data provided by only 17 countries to be of desirable quality [4]. Koester and Galaktionova [56] also discuss the example of FWL in the Russian Federation and conclude that the official FLW data available at the Russian Federal State Statistics Service (Rosstat) are widely misrepresented and are based on approximate estimations. Another example would be the inconsistent FLW definitions between the United States Environmental Protection Agency (USEPA) and the United States Department of Agriculture (USDA), which may lead to a misleading presentation of their national FLW data [89].

Based on the preceding arguments, there is an urgent need for policymakers—especially in developing countries where the main data gap exists [10]—to re-evaluate their statistics’ accuracy and keep their data up-to-date. Therefore, allocating proportional academic budgets to conduct further research on HHFW in NENA seems to be a rational investment that would increase agri-food systems' efficiency while reducing environmental and economic burdens and improving food security and social well-being.

Although obtaining data at a national level would be ideal, the value of sub-national data cannot be underestimated. Our study focused on one food commodity in one city, yet its contribution remains significant. As described in Section 3, Mirfakhrayi et al.'s [42] work that the officials widely cite was also carried out in one city in Iran. HHFW data availability has been persistently expanding, mainly owning to sub-national studies [4]. Policymakers can obtain more pieces of the multifaceted HHFW puzzle by increasing the number of studies at the city and municipality level, the inclusion of which would provide a more accurate evaluation of the status quo.

Meanwhile, it is crucial to implement the latest developed definitions and methods to allow for comparison across studies and geographical settings [90]. For this reason, the UNEP developed the Food Waste Index (FWI) to establish "a consistent approach to monitor SDG Target 12.3" [91] (p. xiii). Although this index still might have some shortcomings—e.g., neglecting the economic value of different commodities' waste [56]—they facilitate the comparability of data across studies and improve the reliability of future data.

Obtaining reliable first-hand data, among other things, would remain a principal challenge ahead of governments and international organizations such as the UNEP for drawing up estimates on food waste. Enhancing statistical knowledge should be an underlying priority for the international community to assess the progress in achieving the SDGs [2]. In the international workshop for capacity building for FLW reduction in the Near East in 2017, enhancing data collection and analytical methodologies was emphasized as the first component for achieving SDG 12.3 [92]. However, as Xue et al. [10] shrewdly stated, gathering data on the quantity of food waste is the first step, and developing effective policies and plans to monitor and reduce food waste must be prioritized.

5. Conclusions

Assessment of HBW in Shiraz revealed an extensive deviation from the official reports in our findings. Due to limited research capacity, the present study focused only on one food commodity in one city. Therefore, the waste results may not be generalized with regard to other food commodities and other locations. Moreover, as discussed in Section 4, the quantification method employed in this study bears a substantial level of underestimation, which may undermine the reliability of our data. However, despite the possible shortcomings and limitations, this study is one of the rare investigations on HBW in Iran based on primary data collection, resulting in detailed datasets. According to the present study, there is a substantial likelihood of bias in the HHFW data that are provided by local governments. As the UNEP generates a major share of its estimates based on the extrapolation of these data, it is crucial to examine whether countries' claims on HHFW are backed up by ample evidence.

Obviously, additional studies on HHFW, especially in developing countries—where the main data gap exists—are necessary in order to gather more data that are compatible with SDG 12.3. The governments should invest in more studies to collect first-hand, up-to-date data to be able to develop effective food waste reduction policies and courses of action. Moreover, we recommend that the UNEP should undertake further empirical research to cross-check and examine the reliability of the data provided by officials and governments. This study reaffirms the necessity of treating the HHFW data that are already available with great caution.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the Shiraz University of Medical Sciences on 30 September 2018, with the code IR.SUMS.REC1397.595.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

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Chapter 6: Article 5

Title of the Article: The Need for Consumer-Focused Household Food Waste Reduction Policies Using Dietary Patterns and Socioeconomic Status as Predictors: A Study on Wheat Bread Waste in Shiraz, Iran

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Abstract

Current household food waste (HFW) reduction plans usually focus on raising consumer awareness, which is essential but insufficient because HFW is predominantly attributed to unconscious behavioral factors that vary across consumer groups. Therefore, identifying such factors is crucial for predicting HFW levels and establishing effective plans. This study explored the role of dietary patterns (DP) and socioeconomic status (SES) as predictors of HBW using linear and non-linear regression models. Questionnaire interviews were performed in 419 households in Shiraz during 2019. A multilayer sampling procedure including stratification, clustering, and systematic sampling was used. Three main DPs, i.e., unhealthy, Mediterranean, and traditional, were identified using a food frequency questionnaire. Results indicated that a one-unit rise in the household's unhealthy DP score was associated with an average increase in HBW of 0.40%. Similarly, a one-unit increase in the unhealthy DP score and the SES score increased the relative likelihood of bread waste occurrence by 25.6% and 14.5%, respectively. The comparison of findings revealed inconsistencies in HFW data, and therefore the necessity of studying HFW links to factors such as diet and SES. Further investigations that explore HFW associations with household characteristics and behavioral factors will help establish contextual and effective consumer-focused plans.

Keywords: household food waste; waste related behavior; sustainable consumption; regression model; food waste occurrence

1. Introduction

Food loss and waste (FLW) occur at different stages of agri-food supply chains, including the reduction in food mass along the production, postharvest, processing, and distribution stages, terminologically referred to as ‘food loss’ [1], as well as food discard at retail, foodservice, and household levels, generally defined as ‘food waste’ [2]. Throughout this paper, the terms ‘food loss’ and ‘food waste’ are used in accordance with the abovementioned definitions. Based on the latest assessments, 14% of food is lost in upstream food supply chains [1], and 17% is wasted at the consumption level [2].

From a lifecycle perspective, the food waste that occurs at the final stages of food supply chains, especially in households, may cause a higher economic and environmental impact than food loss at earlier stages [1]. The food that reaches a household has the footprint of the retail stage in addition to the upstream supply chain, and when it is wasted, the impacts of cooking and domestic storage are also added. In the meantime, the amount of household food waste (HFW) is enormous. The HFW accounts for up to 36% of the total FLW and 65% of food waste [2]. However, it appears that the strategies for reducing HFW are rather general and unfocused, in contrast to the specific plans for tackling the FLW in industrial and business agri-food sectors, including retail and foodservice.

For example, the United States created the FLW 2030 champions initiative in 2016, aiming to halve FLW by 2030 by engaging businesses in food production, processing, retail, and foodservice, but it did not address HFW [3]. In 2019, Germany initiated the national strategy for food waste reduction, which involved all food supply chain sectors, but adopted a general approach toward household consumers [4]. Similar examples can be found in other countries, most of which, at best, proceeded as far as providing general guidelines for reducing HFW [5–7]. HFW reduction guidelines help raise awareness and consciousness with regard to waste generation. However, the role of consumers’ conscious intention to reduce food waste is not as determinative as the role of food-related behavior and habits [8]. Moreover, a major HFW data gap exists in developing countries [9]; meanwhile, many of these countries tend to follow the same strategies formulated for developed countries, which does not necessarily lead to desirable outcomes. Even though guidelines can be effective to some extent, the significance of specific plans tailored for different types of consumers in specific sociogeographical settings cannot be emphasized enough [10]. Such plans scarcely exist.

In the United Kingdom, the action on food waste launched by the waste and resources action programme (WRAP) in 2000 has resulted in tremendous progress toward studying and reducing FLW along food supply chains [11]. In 2014, WRAP published a report that shed light on the association of HFW with household characteristics, e.g., sociodemographic and food-related behaviors [12]. Accordingly, WRAP initiated the “Love Food Hate Waste” campaign, targeting 18 to 35 year-old age groups [13]. However, additional knowledge about HFW attributions is still required to effectively establish further consumer-focused plans.

Determining the household characteristics associated with HFW could also facilitate finding predictors for estimating HFW levels. The HFW quantification methods are either too costly and labor-intensive, i.e., direct measurement and waste composition analysis, or too inaccurate, i.e., recall questionnaire and diary recording [14–20]. The HFW predictors could enable researchers and decision-makers to evaluate the level or occurrence of food waste in households without the complications of waste quantification.

Food is wasted in households for various reasons, such as consumers' gustatory preferences [21], food purchasing and storing [22,23], beliefs and concerns, and food preparation [24–27]. Nonetheless, the question of how the dietary pattern (DP), which plays a central role in consumption behavior, affects the HFW has not yet been established. The USDA defines DP as "the quantities, proportions, variety, or combination of different foods, drinks, and nutrients (when available) in diets, and the frequency with which they are habitually consumed" ([28] p. 9).

Consumers may not be well aware of the environmental and economic impacts of their daily food choices [29,30]. However, the habitual food consumption that constitutes the DPs cumulatively imposes an enormous impact on the environment and the economy in different ways, including through food waste generation [31–37]. Some researchers acknowledged diet as a factor linked with HFW [12,38–46]. However, to the best of our knowledge, no study specifically focused on how HFW is associated with DP.

This paper aimed to investigate whether HFW is associated with DPs. Because the economic situation can impact food waste levels [47–49], the effect of socioeconomic status (SES) on HFW has also been analyzed. Considering the existing food waste data gap at the household level in developing countries [2,9,50], Iran was chosen as an example to conduct the research. This study focused on household wheat bread waste (HBW) in Shiraz, Iran. Wheat bread, hereafter referred to as bread, was chosen because it is the main staple food in the country [51]. Bread is one of the 14 main food items in the Iranians' basic food basket [52], and its average daily intake is known to be 320 g per capita [53]. Shiraz is the capital of Fars, the major wheat-producing province of Iran.

2. Materials and Methods

2.1. Study Design

The survey was performed from December 2018 to August 2019 in Shiraz, Iran. A total of 419 households were interviewed by a group of 13 trained assistants. A household was defined as two or more residents of one house sharing food and its costs. Preferably the mother or the wife was selected as the interviewee because their dietary intake reportedly mirrors the nutritional status of other family members [45,54–57]. If they were unavailable, the person who is usually in charge of the household's food shopping and preparation was interviewed. A three-stage sampling approach was employed, consisting of stratification, clustering, and systematic sampling. The sample size determination and the sampling procedure are thoroughly described by Ghaziani et al. [58].

2.2. Questionnaire

A questionnaire was designed to obtain information on the household level in three sections: (1) demographics and SES, (2) dietary intake, and (3) bread purchasing and wastage. The questionnaire was tested beforehand by conducting 22 interviews with randomly selected households outside the study population to ensure adequate comprehensibility of the questions. The questionnaire sections are described below.

2.2.1. Demographic and Socioeconomic Section

The demographic and socioeconomic questions addressed the household size, income, housing characteristics, house ownership status, and the head of household's occupation and education level. Moreover, binary questions about the ownership of 11 durable assets were asked.

2.2.2. Dietary Section

A 168-item semi-quantitative food frequency questionnaire validated by Esfahani et al. [59] was employed to gather dietary intake data. The questionnaire required the interviewees to report estimations of the intake of each food item, on a daily, weekly, monthly, or yearly basis, within a maximum of a one-year span.

2.2.3. Bread Waste Section

The HBW quantification was performed using a self-assessment approach by means of a recall questionnaire. The focus was on ten commonly consumed bread types, identified according to the Iranian National Standardization Organization [60,61], consisting of two main categories. i.e., traditional bread (TB) and non-traditional bread (NTB). Detailed specifications of the bread types and the HBW amount quantification method are described by Ghaziani et al. [58].

2.3. Statistical Analysis

IBM SPSS Statistics version 25 [62] was used to analyze the data, with a significance level of $p < 0.05$. The socioeconomic, dietary, and HBW data analyses are explained below.

2.3.1. Socioeconomic Data Analysis

The socioeconomic data were analyzed based on the method explained by Vyas and Kumaranayake [63] by applying principal component analysis (PCA) to the socioeconomic variables. The factor scores of the principal component (PC) with the highest eigenvalue of 4.12, explaining 18.75% of the variance in data, were selected as weights of the SES indicator variables. The SES score for each household was computed according to the equation below. Higher scores represent households with higher SES. For a simpler description of the data, the households were grouped by assigning cut-off values for percentiles of the study populations. The percentiles were set according to Filmer and Pritchett [64], identifying the lowest 40% as poor, the next 40% as middle class, and the top 20% as rich.

$$y_i = \sum_{n=1}^{22} x_n \, C_n$$

where y is the SES score, i is the household's number (with i = 1 to 419), x_n is the household's value for the nth SES indicator, and C_n is the PC load of the nth SES indicator.

2.3.2. Dietary Data Analysis

The participant's total intake of the 168 food items of the FFQ was separately converted to gram intake per day. The food items were merged into 30 categories based on their nutrient content, researchers' opinions, and the study of Hosseyni Esfahani et al. [65], presented in Table 1. Each participant's total daily intake of different food categories was calculated by totaling daily intakes of their corresponding food items. PCA was applied to find the main components responsible for most of the variance in data, assigning the food categories as variables.

Table 1. Food grouping used in principle component analysis of the 168 food items in the food frequency questionnaire for the identification of dietary patterns.

Food Category	Food Item
Processed meat	Sausages
Red meat	Lamb, beef, veal, minced meat, hamburger
Lamp/veal organ meat	Tripe, heart, liver, kidney, head, feet, tongue, brain
Fish	All fish, fresh or canned
Poultry	All chicken parts
Eggs	Eggs
Hydrogenated fat with animal origin	Cream, butter, tallow, animal fat
Coffee	Coffee
Tea	Tea
Fruits and fruit juice	Apple, apricot, banana, cantaloupe, cherries, citrus juice, dates, fresh fig, fresh fruits and vegetable juice, grapefruit, grapes, greengage, kiwi, lemon juice, vinegar, and verjuice, lime, mulberry, orange, peach, pear, Persian melon, persimmon, plum, pomegranate, strawberry, sweet lemon, tangerine, watermelon
Refined grains	White bread (lavash, baguette, bun, broetchen (bread rolls), mini baguette, toast), rice, pasta/spaghetti, noodles/vermicelli, wheat flour
Whole grains	Wheat whole grain bread (sangak, taftoon, barbari), other whole grain bread types, barley, oatmeal
Legumes	Beans, chickpea, lentil, mung bean, soybean meal, split pea
Low-fat dairy products	Low-fat and skimmed milk, low-fat yogurt, kashk, yogurt drink (doogh)
High-fat dairy products	High-fat, whole and chocolate milk, cheese, high-fat yogurt (incl. concentrated and creamy), ice cream
Margarine and vegetable hydrogenate fat	Margarine, vegetable hydrogenated fat
Other vegetables	Bell pepper, carrot, chili pepper, cooked and raw celery, cooked and raw tomato, cooked green bean, cooked green pea, cooked mushroom, cooked spinach, cucumber, fresh herbs, lettuce, pumpkin, raw and cooked leafy vegetables, raw and fried onion, raw garlic, tomato paste, turnip, zucchini or eggplant
Potato	Baked potato
Salty snacks	French fries, puffs, potato chips, salty crackers
Cruciferous vegetables	Red and white cabbage, other kinds of cabbage
Olive	Olive, olive oil
Pickle	Pickles, salted vegetables
Dried fruits	Dried mulberry, raisin, others (dried fig, follicle, etc.)
Oil	Vegetable oils (except olive)
Nuts	Almond, peanut, pistachio, seeds, walnut
Sweets and desserts	Biscuits, candy, chocolate, gaz, honey and jam, noghl, pastries (non-crème and creamy), sohan, sponge cake, cookies other cakes, sugar, sugar candy, toffy
Sugary beverages	All soft drinks and industrial sugar sweetened beverages
Mayonnaise	Mayonnaise
Diet coke	Diet coke

The adequacy of the correlation matrix of the predefined food categories for PCA was examined using the Kaiser–Meyer–Olkin Measure (KMO) test. The test showed a significant result with a *p*-value lower than 0.001 and a KMO value of 0.708, indicating acceptable adequacy for conducting PCA [66].

Based on the initial results and visual inspection of the scree plot, three components with the highest eigenvalue (4.025, 1.914, 1.747), explaining 25.64% of the variance, were identified for extraction. The rotation method was set on Varimax with Kaiser normalization. Coefficient factors below the minimum absolute value of 0.2 were suppressed, and other values were used to identify the food categories with primary loads in each component. Ultimately, three main DPs were identified based on the nutritional interpretability of food categories loaded together within each component and according to Mirmiran et al. [67]. Each household received a score for each DP, which was calculated according to the equation below. The mean score values of each DP were compared across the SES classifications using Least Significant Difference (LSD) tests.

$$y_{ij} = \sum_{n=1}^{30} x_n L_{ni}$$

where y is the DP score, i is the component number representing each DP (with i = 1 to 3), j is the household's number (with j = 1 to 419), x_n is the daily intake of the nth food category, and L_{ni} is the load of the nth food category within the ith DP.

2.3.3. Bread Waste Data Analysis

The waste mean values for each bread type were calculated as described by Ghaziani et al. [58]. The mean waste value for TB and NTB were calculated as the average of the waste amounts of all bread types within their respective category. Paired samples and independent samples t-tests were implemented to compare the mean waste across bread categories.

2.3.4. Regression Models

The HBW amount relationship with the DP and SES scores was analyzed using multiple linear regression by assigning the waste amount as the dependent variable and the three DP scores and the SES score as regressors. Additionally, a binary logistic regression model analyzed the occurrence/non-occurrence of bread wastage depending on the variation in the DP and SES scores. Moreover, consuming or not consuming NTB in relation to DP and SES scores was explored using binary logistic regression.

3. Results

3.1. Demographics and Socioeconomic Status

A total of 1548 people lived in the studied households, with an average household size of 3.69 (SD = 1.22). Table 2 indicates which members were interviewed, responsible for household nutrition and heads of the households. As intended, mothers who are most often responsible for food preparation were mainly interviewed. The majority of households were male-headed. The table also shows the proportion of different occupations and education levels among the heads of households. Moreover, the proportion of different SES classes is presented.

Table 2. Demographic and socioeconomic summary of the studied households (n = 419).

Variables		Frequency	
		n	%
Respondent	Mother	376	89.7
	Father	14	3.3
	Daughter	22	5.3
	Other	7	1.7
In charge of food preparation	Mother	385	91.9
	Father	8	1.9
	Daughter	16	3.8
	Other	10	2.4
Head of the household	Mother	36	8.6
	Father	370	88.3
	Other	13	3.1
Occupation [a]	Unemployed	49	11.7
	Skilled worker	105	25.1
	Employee	116	27.7
	Retired	126	30.1
	Professional	23	5.5
Education [a]	Illiterate or primary school	94	22.4
	High school or diploma	229	54.7
	University degree	96	22.9
SES classes	Poor	130	31.0
	Middle class	172	41.1
	Rich	117	27.9

[a] Variables belonging to the head of household.

3.2. Dietary Patterns

Table 3 shows details regarding the load of food categories on each component. According to nutritional interpretation of the components, three DPs were identified, with component 1 being unhealthy, 2 Mediterranean, and 3 traditional. The household score for each DP indicates their tendency to implement that DP habitually.

Table 3. Factor-loading rotated matrix and Eigenvectors for the three identified dietary patterns.

Food Groups	Components		
	1 Unhealthy	2 Mediterranean	3 Traditional
Sugary beverages	0.679		
Salty snacks	0.676		
Mayonnaise	0.511		0.282
Sweets and desserts	0.480		
Refined grains	0.430		0.349
Red meat	0.414		
Hydrogenated fat with animal origin	0.396		
High-fat dairy products	0.389		
Processed meat	0.357		
Organ meat			
Olive		0.552	
Cruciferous vegetables		0.552	
Green leafy vegetables		0.540	0.494
Nuts	0.247	0.505	
Fish	0.223	0.503	
Dried fruits	0.269	0.501	
Fruits and fruit juice		0.435	0.368
Coffee	0.330	0.372	
Whole grains		0.358	
Low-fat dairy products		0.335	0.267
Tea			
Other vegetables		0.408	0.632
Eggs			0.494
Legumes		0.202	0.479
Pickle			0.441
Poultry	0.246		0.395
Potato			0.387
Margarine			0.362
Oil			0.256
Diet coke			

Table 4 presents how the DP mean scores vary across SES classes. The LSD test suggests that the unhealthy mean score was higher in the rich class. Additionally, the Mediterranean scores were significantly higher in richer SES classes. A reverse outcome was observed in the traditional scores, with the richest class scoring lowest.

Table 4. Means and standard deviations of DPs among different SES classes.

SES Classes	***n***	**DP Score Values**					
		Unhealthy		**Mediterranean**		**Traditional**	
		Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***
Poor	127	−0.205 [a]	0.709	−0.380 [a]	0.741	0.109 a	1.198
Middle-class	170	−0.038 [a]	0.963	0.063 [b]	1.120	0.021 ab	0.930
Rich	115	0.282 [b]	1.244	0.327 [c]	0.930	−0.152 b	0.836

Different superscript letters indicate a significant difference at the $p = 0.05$ among the means in each column. The group sizes are unequal. The harmonic mean of the group sizes was used. SES = socioeconomic status; n = number; DP = dietary pattern; SD = standard deviation.

3.3. Bread Waste

Three respondents did not answer the HBW questions (0.72% missing). The total average HBW was 1.80% (n = 416, SD = 3.36). The mean waste values were 1.70% (n = 416, SD = 3.70) and 2.50% (n = 304, SD = 5.26) for TB and NTB, respectively. The paired sample t-test did not indicate significant differences between the two bread categories. Because the paired comparison excluded the non-NTB-consumers, an independent samples t-test was employed, revealing that the NTB waste was significantly higher than the TB waste ($p = 0.016$).

Figure 1 illustrates the frequency of bread consumption and wastage occurrence in the studied households based on bread categories. Out of 416 respondents, 50.48% reported that they do not waste bread. All 416 households consume at least one type of TB, among which 56.97% reportedly did not generate any TB waste. A total of 73.08% of the households consume NTB, of which 66.12% claimed that the NTB is not wasted in their households.

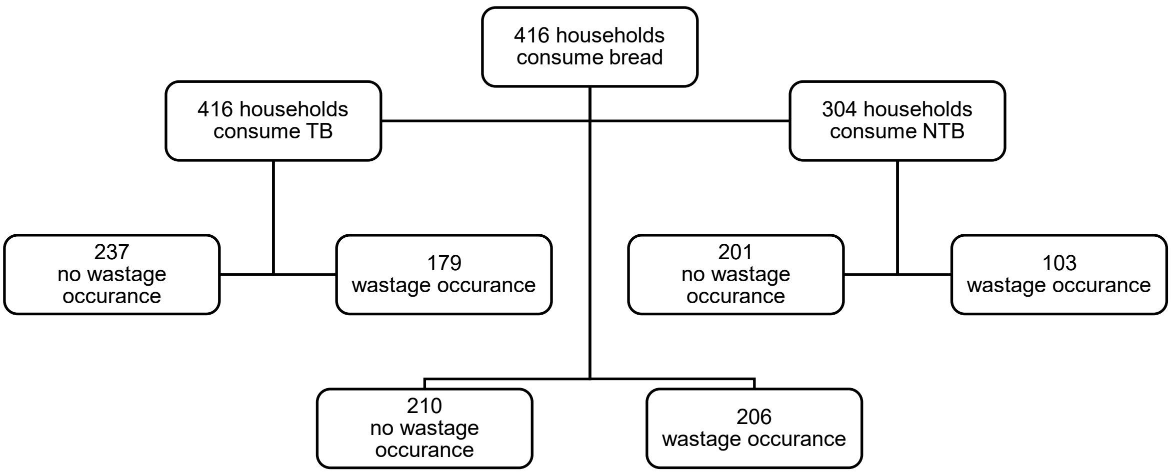

Figure 1. Schematic presentation of the number of households that consume bread and the number of households where bread wastage occurs, grouped based on bread categories; TB = traditional bread, NTB = non-traditional bread.

3.4. The Effects of the Households’ Dietary Patterns and Socioeconomic Status on Bread Waste

Table 5 presents the results of multiple linear regression models for predicting the HBW amount by the variation in the DP and SES scores. The models revealed that the unhealthy DP had a significant positive influence on the waste amount. This could mean that, for a one-unit increase in the unhealthy DP score, the HBW amount increases by 0.40% on average, supposing that other variables are constant. The Mediterranean and traditional DPs were insignificant in the regression models. The regression model for TB waste amount detected a marginally significant coefficient for the unhealthy score, implying that the unhealthy diet score variation might be able to predict the TB waste amount. The NTB waste was not affected by any DPs. Moreover, the effect of SES on the HBW amount of all categories was insignificant.

Table 5. Multiple linear regression coefficients and significances for predicting the HBW amount.

Dependent Variables	DPs						SES	
	Unhealthy		Mediterranean		Traditional			
	Coef	*p-value*	*Coef*	*p-value*	*Coef*	*p-value*	*Coef*	*p-value*
BW amount	0.407	0.017	0.102	0.563	−0.145	0.386	−0.006	0.954
TBW amount	0.355	0.060	0.095	0.625	0.117	0.526	−0.052	0.641
NTBW amount	0.268	0.364	−0.166	0.587	−0.423	0.157	0.110	0.561

BW = bread waste; TBW = traditional bread waste; NTBW = non-traditional bread waste; DP = dietary pattern; SES = socioeconomic status; Coef = coefficient.

Because not all households consume NTB, a binary logistic regression model was employed to assess the predictability of the NTB consumption when the DP and SES scores vary (see Table 6). The outcome revealed that by a one-unit rise in a household’s unhealthy and Mediterranean scores, the relative probability of consuming NTB increases by 79.3% and 49.6%, respectively. Consuming NTB could not be predicted by the traditional DP and SES.

Table 6. Binary logistic regression weights and significances for predicting NTB consumption.

Dependent Variables	DPs						SES	
	Unhealthy		Mediterranean		Traditional			
	Expo Coef	*p-value*	*Expo Coef*	*p-value*	*Expo Coef*	*p-value*	*Expo Coef*	*p-value*
NTB consumption	1.793	0.001	1.496	0.010	0.914	0.432	1.014	0.845

NTB = non-traditional bread; DP = dietary pattern; SES = socioeconomic status; *Expo Coef* = exponential coefficient.

As most of the factors in linear regression could not predict the HBW amount, binary logistic regression models were applied to examine whether the variation in the variables could predict the wastage occurrence. Table 7 shows the likelihood of bread wastage by variation in DP and SES. In line with the multiple linear regression results for the waste amount, the unhealthy diet positively impacted bread wastage, meaning that raising the unhealthy diet score by one unit would increase the relative probability of wastage occurrence by 25.6%. Meanwhile, the effect of Mediterranean and traditional DPs remained insignificant. Additionally, no DP impacted the TB and NTB wastage.

Table 7. Binary logistic regression weights and significances for predicting bread wastage occurrence.

Dependent Variables	DPs						SES	
	Unhealthy		Mediterranean		Traditional			
	Expo Coef	*p-value*	*Expo Coef*	*p-value*	*Expo Coef*	*p-value*	*Expo Coef*	*p-value*
Bread WO	1.256	0.046	1.114	0.329	1.015	0.887	1.145	0.028
TB WO	1.168	0.142	1.050	0.649	1.046	0.660	1.113	0.082
NTB WO	1.211	0.103	1.025	0.841	0.904	0.433	1.232	0.008

WO = wastage occurrence; TB = traditional bread; NTB = non-traditional bread; DP = dietary pattern; SES = socioeconomic status; Expo Coef = exponential coefficient.

The SES score significantly explained the wastage occurrence such that a one-unit rise in the SES score would increase the relative odds of wastage by 14.5%. The impact of the SES on the TB wastage was marginally significant (11.3% relative chance of wastage per one-unit SES increase), and on NTB wastage was significant (a one-unit rise in the SES score would increase the relative odds of the NTB wastage by 23.2%).

4. Discussion

The current study revealed that HBW could be influenced by DP and SES. The effects of DP and SES on HBW were assessed using two types of models, i.e., multiple linear regression and binary logistic regression. The first model examines the predictability of waste amount depending on the variation in the main factors, namely, DPs and SES. The latter predicts the relative probability of HBW occurrence if the regressors' values change. The linear regression outcome revealed that explanatory variables other than unhealthy DP do not influence the BW amount. This outcome could be a result of limited waste values or small NTB subsamples in the dataset from this study. The reasons for obtaining such limited waste amounts are thoroughly discussed by Ghaziani et al. [58]. These reasons may include inconsistencies in food waste conceptual and methodological frameworks, change in domestic food storage methods, the unprecedented economic recession in Iran, bread quality improvement, and cultural stigmatization of bread wastage [58]. More than half of the respondents reported that they do not waste bread (zero-wasters). Because the linear regression model only indicated a significant effect of one regressor on the waste amount, a binary logistic regression model was employed to detect possible influences of other variables on bread wastage occurrence, as measuring the bread wastage occurrence or non-occurrence is less error-prone than measuring the exact waste amount.

Both the amount and occurrence of HBW were positively influenced by unhealthy DP, meaning households with higher unhealthy DP scores were likely to waste more bread, and bread wastage was more likely to occur in their houses. Moreover, between the two bread categories, TB waste could be positively affected by the unhealthy DP score, as the coefficient was marginally significant. The Mediterranean and traditional DPs and SES played no role in the variation in the HBW amount, regardless of bread categories. However, the binary logistic regression model detected a significant effect of SES on HBW occurrence, meaning that bread wastage was more likely to occur in households with higher SES.

In general, some studies confirmed that HFW could be associated with diet and eating habits without investigating the direct relationship between diets and HFW [8,39,40,44,68,69]. Other researchers have acknowledged food choices and shopping preferences as diet-related factors influencing HFW [40,70]. Two studies analyzed the change in HFW in relation to diet [45,46]. Conrad et al. [46] found that higher diet quality is associated with higher HFW in the United States using linear regression models, but HBW (grains and mixed grain dishes) was not significantly influenced. In a similar study in Canada, Carroll et al. [45] only found that daily fruit and vegetable waste amount in households was positively associated with the parents' diet quality, while the diet quality effect on the waste amount in other food groups, including bread, was insignificant.

In this study, the diet quality was not analyzed, and other food groups such as fruits and vegetables were not included either. The reason for choosing DP over diet quality was that DP is more identifiable as a predictive factor for designing food waste reduction policies and intervention programs. Bread was chosen due to its high importance (see Section 1), while other food groups were not included due to logistical constraints. However, if the households with higher unhealthy DP scores are assumed to have a lower diet quality based on their predominant food choices (see Table 3), the findings from the present study could be compared to the ones of Carroll et al. [45] and Conrad et al. [46]. Given this assumption, the current results contradict Carroll et al. [45] and Conrad et al.'s [46] findings regarding the link between HBW and dietary quality.

However, a common finding in Carroll et al. [45] and Conrad et al.'s [46] studies and the current one was that food choice could be a major factor affecting HFW. The present study revealed that the NTB mean waste value was higher than the TB mean waste. Meanwhile, the households with higher unhealthy DP scores were more likely to consume NTB. The evidence suggests that mismanagement in shopping for and preparation of perishable foods would lead to a high level of HFW [40]. Based on anecdotal evidence, the NTB in Shiraz is usually sold in packed units, kept at room temperature, and consumed fresh. Meanwhile, TB bread is normally purchased as pieces and stored in a freezer [58]. Failing to consume the whole package is a reason for food wastage, especially in smaller households [22]. Furthermore, many consumers in Shiraz discard the inner crumbs of some NTB types, such as baguette or hamburger bun, which can be why NTB waste is higher than TB [17]. Ergo, one reason for wasting more bread in households with higher unhealthy diet scores could be that their choice of bread involves potentially higher waste generation. Interestingly, Conrad et al. [46] and Carroll et al. [45] argued that the higher HFW amount in the households with higher diet quality is basically due to higher consumption of fruits and vegetables, which perish more rapidly than most food groups. Therefore, food choice was evidently an influential factor for HFW in all three studies.

The general inadvertency toward food consumption in consumers with higher unhealthy DP scores could offer a potential explanation for their higher HBW amount in the present study. Consumers with a high tendency toward unhealthy diets have a relatively low level of consciousness about their health and food consumption behaviors [71,72]. Parizeau et al. [41] found that the households with a member who has a special diet, such as vegetarian or diabetic, have more consciousness about their food consumption and tend to adopt HFW reduction strategies. Consumers concerned about sustainable and healthy food consumption are more willing to reduce or reuse food waste [73]. On the other hand, consumers' lack of concern for their food-related behavior may cause them to not have the intention to restrict HFW [8]. Of course, this may not be the case in certain circumstances, as consumers with higher diet quality generated more HFW in the United States and Canada [45,46]. This disparity could be due to differences in other HFW-relevant aspects, such as religious, cultural, psychographic, and socioeconomic factors [73–75]. Therefore, using a single aspect to compare HFW results may reveal contradictions.

For example, dietary habits vary strongly based on psychographics and cultural factors [76–81]. The dichotomy between the present findings and the studies in the United States and Canada [45,46] regarding HBW's link to SES also exists in the link between SES and diet across the two geographical regions. The current results indicated that the average unhealthy diet score was lower in the bottom socioeconomic classes. This is in good agreement with another study in Iran by Abdollahi et al. [82]. Meanwhile, evidence suggests that North American households with higher SES tend to adopt healthier dietary habits [83–86].

Other inconsistencies exist among the findings regarding HFW's link to SES. Other studies support the present findings that bread wastage is more likely in households with higher SES [87–90]. On the contrary, a study in Brazil showed that low SES consumer groups generated more HFW due to poor food purchasing and preparation management despite their willingness to cut expenses by consuming food frugally. In another study in Germany, Herzberg et al. [22] found that socio-demographic variables did not influence the HFW amount. All in all, the dynamic between HFW and other factors such as DP and SES highly varies across consumer groups with different demographic and socio-cultural backgrounds. Therefore, possible explanations for such dynamics must be assessed based on the specific circumstances of the target populations.

The positive relationship between HBW and SES in the present study could be attributed to the poorer households' overall financial circumstances regarding bread consumption. It has previously been reported that bread has a higher share in the composition of the family food basket among Iranian households in the lower socioeconomic classes [52,91]. Such households have a lower purchasing power and, therefore, tend to avoid over-purchasing [47,49] while utilizing their food frugally [92,93]. A study from Greece revealed that households with financial hardships could reduce HFW to restrict their spending [94]. For instance, financial constraints drive consumers to consume food products in suboptimal conditions, which leads to more HFW avoidance [95]. These explanations imply that in the current study, zero-wasters were mostly the poorer households who intended to cut expenses by efficiently utilizing their food resources, with bread being the most important. Nevertheless, a study on HFW in Iran showed that households with higher SES have a higher intention to reduce HFW [96]. This contrast attests to the precedence of behavioral factors over the conscious intention to avoid HFW.

Food-related behaviors are often automated and unconscious [97]. Consumers may not even specifically realize the actual reasons for wasting food [22]. Many consumers have no clear awareness of the HFW quantity or even its occurrence [18,98]. Generally, wasting food is stigmatized in most cultures [99–101], and common sense confirms that it has no economic justification. Most consumers are concerned, at least to some extent, about the HFW issue [94,102]. Therefore, it seems that everyone could agree on the necessity of avoiding HFW.

A recent qualitative study involving 23 Chinese household interviews revealed that consumers' psychological consciousness and religious beliefs could lead to HFW minimization [103]. However, the conscious intention to avoid HFW is not sufficient motivation to avoid HFW. For example, the religious teachings of Islam abominate wasting food [104]. Nevertheless, as a famously religious country, Saudi Arabia ranks fifth globally in terms of HFW, with 105 kg per person annually [105]. In many Muslim countries, substantial food amounts are wasted during religious occasions such as Ramadan [106]. Aktas et al. [107] stated that the high level of food waste during Ramadan is mainly due to changes in food consumption behavior.

Overall, the HFW cannot be attributed to one or two factors, and the number and the types of factors and their impact on HFW differ depending on geographical, demographical, and cultural settings. Households may be the most complicated FLW hotspots along food supply and consumption chains due to the multifaceted nature of food consumption behaviors [108]. It is worth reiterating that most of the existing HFW prevention guidelines are rather general and aimed at increasing consumers' awareness of the topic [3–7]. As stated in Section 1, most existing guidelines are based on studies and data from developed countries, while a major data gap exists in the developing world [9]. Raising awareness on the issue of HFW is essential but insufficient for achieving satisfactory reduction scales [109].

Imitating general guidelines that are formulated based on limited data from specific sociogeographical regions (mostly developed countries) would not necessarily result in satisfactory outcomes elsewhere. Besides gaining a proper understanding of HFW and its drives, different regions have to set commensurate objectives to be able to strategize efficient FLW reduction. For example, in developed countries with high food security levels, the focus will likely be more on the environmental aspects of FLW by moderating the surplus supply, while less-developed countries may need to focus on improving food security through reusing FLW to feed vulnerable groups [1]. Therefore, the need for devising consumer-focused HFW reduction strategies for each target population cannot be stressed enough. For developing an effective consumer-focused HFW reduction strategy, three steps are essential, namely:

1. finding the factors that affect HFW level and generation and identifying how they make an impact;
2. grouping consumers based on HFW-related characteristics;
3. formulating strategies and policies for HFW reduction focused on behavioral change.

Discovering the behaviors linked to HFW is the key to finding consumer-focused waste prevention strategies. In a systematic review, Schanes et al. [110] categorized the behavioral practices associated with HFW into eight groups, including:

1. planning (i.e., meal planning and checking food inventories before shopping);
2. shopping;
3. storage;
4. cooking;
5. eating;
6. managing leftovers;
7. assessing edibility;
8. disposal.

Nonetheless, more waste-related factors and simpler household characteristics must be identified to act as HFW predictors. Examples of such indicators may include DP, SES, and household age and size. Studies suggested that younger households waste more food than older households [25,69,98,111], or HFW amount is higher in larger households than in smaller ones [18,22,41,88,112,113]. Implementing HFW predictors may facilitate creating proper incentives for avoiding HFW among specific consumer groups.

Because a combination of factors explains the HFW [70], household consumers can be grouped based on multiple waste-related characteristics. Grouping household consumers based on such characteristics can benefit the decision-makers in two ways: first, by using the factors as predictors for estimating the quantity and quality of HFW in different segments of a population; and second, by identifying which factors are most relevant to focus on for formulating consumer-focused HFW reduction plans. Grouping consumers must be based on conveniently measurable factors to facilitate the implementation of the plans. For example, in the American and Canadian studies [45,46], diet quality was used to predict HFW levels, which requires comprehensive data collection. Dietary data in the present study was collected using a food frequency questionnaire, which is also a time and labor-intensive method. However, proxy yet desirable results can be obtained from simpler methods such as food screening [114,115] or simpler questionnaires [116] to project HFW-related factors such as diet quality or dietary patterns. Ultimately, tools and methods for implementing each strategy development step must be chosen according to the available resources.

In the last instance, HFW reduction policies and strategies can be designed for each consumer group, focusing on behavioral change while raising awareness about the HFW issue in parallel. Visschers et al. [111] suggested that food waste reduction programs should target consumers' behavior in order to gain better results, which seems to be a reliable approach. Zamri et al. [117] recommended that future food waste reduction campaigns should focus on faith to encourage behavioral changes. Moreover, incentives for food waste reductions can simultaneously focus on other beneficial behavioral aspects, such as improving dietary health [45]. Nevertheless, governmental control may lead to lowering consumers' intention to reduce food waste [118]. Therefore, authorities must take a motivating approach rather than imposing certain policies on the community. Generally, depending on the objectives of a food waste reduction plan and how it is implemented, its direct or indirect impact on the food and nutrition security for different groups of people may vary, and not everyone reaps the benefits [119]. Hence, achieving desired objectives will require thorough assessments of the effects and consequences of each strategy.

As an example, based on the current results, the authorities in Shiraz could assume that bread is probably wasted more in richer districts, particularly among the households with a high tendency toward unhealthy diets and possibly due to higher consumption of NTB. One approach would be to promote waste-reducing actions such as supplying non-packaged NTB in these regions. Moreover, it has been suggested that HFW reduction strategies with multiple objectives that overlap environmental, economic, and social aspects could result in optimal accomplishments [120]. Therefore, implementing a factor such as DP would provide the opportunity to focus not only on waste but also on the health aspects of consumption behavior.

For example, encouraging shifting unhealthy diets to healthier alternatives may reduce HBW in Shiraz while improving the communities' dietary health.

5. Conclusions

HFW has become a dilemma with adverse environmental, social, and economic impacts. Although most consumers are unwilling to waste food at home, the HFW still accounts for a substantial share of the total FLW. The amount and occurrence of HFW are attributed to multiple unconscious behavioral factors and household characteristics. Summing up the results, it can be concluded that the HBW amount in Shiraz is associated with DP and its occurrence varies depending on the households' SES. The inconsistency between the findings presented in this paper with other studies emphasizes the need for developing HFW reduction strategies tailored to specific consumer groups based on their HFW-related characteristics. This outcome could widen the current knowledge of HFW and provide further insight to decision-makers to plan better for reducing HFW.

Nonetheless, a limitation of the current study was that the focus was only on one food commodity, mainly due to limitations in time and research resources. However, the overall findings of the present study corroborate previous results that HFW is, in fact, linked with diet. Additionally, the silver lining of the specificity of this study was that focusing on one food commodity can enable a deeper insight and an exclusive evaluation. Moreover, to the best of our knowledge, this study is the only investigation specifically focused on the relation between HFW and DP based on detailed primary nutritional data. The evidence from this study could persuade the decision-makers and researchers to advert their focus on DP and SES as predictors along with other factors influencing HFW.

Further studies should concentrate on specific food commodities in distinct regions to facilitate the selection of effective objectives and strategies for HFW reduction plans in the respective settings. In this framework, discovering the behavioral aspects and household characteristics that affect HFW is the key. Therefore, further research should focus on more food groups and commodities, additional HFW behavioral drives, and more precise HFW quantification methods. It is essential to assess the HFW issue from multiple perspectives and establish solutions specific to different cultural and geographical settings. Meanwhile, long-term success rests upon reevaluating the HFW and its affecting factors anew as circumstances change, and accordingly, the adjustment of the objectives and strategies have to be taken into consideration.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

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Chapter 7: General Discussion

1. Overview

This chapter presents a comprehensive discussion of the cumulative dissertation, starting with a revisit and summary of the six research objectives outlined in Chapter 1. It provides an overview of the study design and methodologies employed, underscoring their role in accomplishing the research objectives. A major focus of this chapter is placed on examining the pros and cons of the study approaches and offering recommendations to foster a balanced perspective. In order to support this analysis, evidence from international literature is utilized. A dedicated subchapter addresses the limitations encountered during the research process and offers important considerations for future studies.

Additionally, the chapter synthesizes the key findings and implications derived from the articles presented in Chapters 2 to 6 while also providing recommendations and suggesting directions for future research in the field of food loss and waste (FLW). While the results of each individual article have been extensively discussed within their respective chapters, this discussion focuses on the collective outcomes and their alignment with the research objectives. The final section of this chapter offers general remarks and recommendations based on the experience gained from the doctoral dissertation, providing insights for further advancements in the field of FLW.

2. Methodological Approach: A Framework to Achieve Research Objectives

The present doctoral study aimed to address six primary research objectives that revolved around exploring loss and waste throughout the wheat lifecycle, with a specific focus on wheat bread as the final product. The study concentrated on wheat production in Fars province and bread consumption in its capital, Shiraz, recognizing the province’s significance as a major wheat-producing region in the country. The research objectives included (1) identifying and mapping the wheat lifecycle, (2) identifying loss and waste hotspots, (3) improving the accuracy of the methods used for FLW quantification, (4) quantifying the loss or waste and examining the reliability of existing data, (5) investigating underlying reasons and associated factors, and (6) exploring potential solutions to reduce wheat and bread loss and waste.

This doctoral study employed a combination of qualitative and quantitative approaches to effectively address the research objectives. Data collection was accomplished through two surveys, each serving a distinct purpose. Additionally, a lab experiment was conducted to simulate common consumption recipes and measure the resulting waste. Figure 1 provides an overview of the specific areas of the wheat and bread lifecycle (WBL) that each survey focused on.

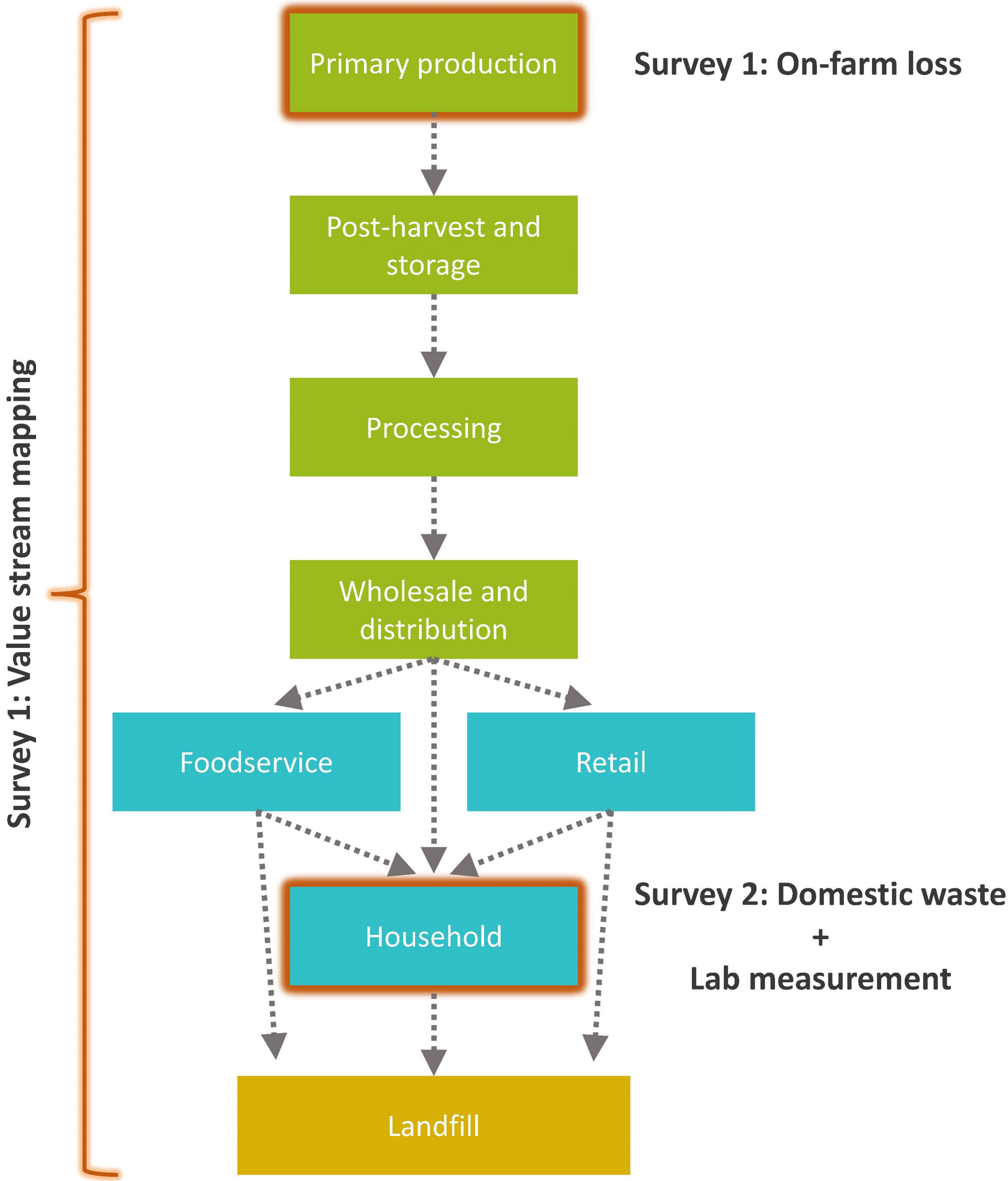

Figure 1. The focus of the conducted surveys based on specific areas of the wheat and bread lifecycle.

The first survey in this study was designed as an exploratory means to gain a comprehensive understanding of the structure of the WBL and the prevailing status of wheat loss and bread waste. By utilizing a qualitative approach, the survey provided a deep understanding of the issue and allowed for a thorough exploration of the study's scope. Qualitative studies have proven to be particularly valuable in research on FLW, as further elaborated by Gascón et al. [1] and Chambers [2]. Gascón et al. [1] argue that the efficacy of comprehending FLW generation lies in adopting a qualitative perspective rather than relying solely on quantification. According to Chambers [2], using qualitative data enables the identification of associations and causal links. This can be particularly useful in researching a multifaceted issue such as FLW.

The first survey effectively addressed Research Objectives 1, 2, 5, and 6 by providing valuable insights into the wheat lifecycle, identifying loss and waste hotspots, exploring underlying reasons and factors associated with on-farm wheat loss, and examining potential solutions for reducing these losses. Through this survey, a comprehensive cradle-to-grave depiction of the WBL in Fars province was obtained. The findings highlighted that farms, foodservice establishments, and households were significant contributors to loss and waste throughout the WBL. Moreover, the results also revealed substantial data gaps concerning on-farm wheat loss and household bread waste (HBW). These research outcomes are presented in detail in the peer-reviewed article presented in Chapter 2. The qualitative exploration of wheat loss at the farm level, as outlined in the peer-reviewed article presented in Chapter 3, sheds light on key reasons for on-farm wheat loss, such as seed overuse, pest infestation, and improper harvesting practices. Furthermore, potential solutions for reducing on-farm wheat loss were discussed, including improving farmers' access to suitable machinery and enhancing their technical farming knowledge through the empowerment of agricultural cooperatives. The outcomes of the first survey emphasized the importance of explicitly targeting households in FLW research. As a result, the second survey was strategically designed to investigate bread waste at the household level.

The second survey primarily utilized a quantitative approach, complemented by the collection of partial qualitative data. Its main objectives were to quantify HBW and examine its correlation with important household characteristics, such as dietary patterns and socioeconomic status. The advantages of this approach have been twofold. Firstly, the utilization of quantitative data enabled a comprehensive assessment of the extent of HBW, facilitating the measurement and comparison of waste levels across different households [3]. This quantitative approach also facilitated the exploration of the relationship between HBW and dietary patterns as well as socioeconomic status through multiple regression modeling. Secondly, the collection of supplementary qualitative data provided valuable insights into the underlying factors contributing to bread waste [4], including consumer behaviors and domestic storage practices. The questionnaire for the second survey was carefully designed, and its comprehensive structure is provided as an annex to the dissertation. Saw et al. [5] emphasize the importance of ensuring reliability and validity in questionnaire design, including addressing content, construct, and criterion validity for different types of questionnaires.

The questionnaire consisted of three sections: bread waste, dietary intake, and socioeconomic status. The order of these sections was thoughtfully determined. Prior to the survey, the questionnaire underwent testing to ensure the clarity of the questions. Thirty interviews were conducted outside the study sample to assess participant understanding and responses. Encountering challenges in convincing participants to participate and establish trust, a small monetary gift was offered as an initial incentive. This approach aligns with the findings of Holm et al. [6], who discovered that financial incentives can positively influence trust-related behavior. The utilization of this approach yielded a notable advantage by substantially enhancing the response rate among the selected households, thereby reducing the inherent bias often encountered in population studies [7]. Nevertheless, it is crucial to recognize the accompanying disadvantage of elevated research costs associated with this methodological choice.

Additionally, the structure and wording of questionnaire items can impact the level of trust expressed by respondents [8]. In order to address participants' hesitancy in answering potentially sensitive questions, the questionnaire was structured to begin with the least sensitive information, such as bread purchasing and consumption behavior. This decision also ensured the collection of bread waste-related data even if a participant refused to continue the interview. Subsequently, dietary questions were asked. As the interview progressed and reached the section on socioeconomic status, which was the most sensitive information, participants felt more at ease in responding. This gradual approach helped build trust throughout the interview process, ensuring participants' willingness to provide answers to all the questions. Consequently, a noteworthy advantage of this approach was the successful attainment of a comprehensive dataset with minimal missing information. Nevertheless, it is worth noting that the inclusion of a substantial number of questions and the extended duration of the interviews may have potentially affected the response quality [9].

In addition to the questionnaire survey, a complementary lab experiment was conducted to enhance the accuracy of the employed quantification method. The inclusion of this lab experiment, in conjunction with the second survey, facilitated the achievement of Research Objective 3, as outlined in Chapter 4. The study findings revealed that the estimates obtained solely from the survey had the potential to be underestimated, with correction factors ranging from 1.24 to 1.80 applied to provide a more precise estimation of HBW, as expounded upon in the article presented in Chapter 5. The significance of improving the precision of food waste quantification methods is highlighted by Withanage et al. [10], emphasizing the need for standardized and accurate methodologies in quantifying household food waste (HFW) to ensure the comparability of results.

Furthermore, the survey employed a quantitative approach to collect firsthand data on bread waste quantities, allowing for a comprehensive assessment of the magnitude of the issue, as presented in Chapter 5. In doing so, it effectively addressed Research Objective 4. Quantifying FLW is essential for monitoring progress toward achieving Sustainable Development Goal

(SDG) 12.3 [3,11,12]. The survey's findings were compared with previous official reports and scientific studies to evaluate the reliability of existing data and identify any discrepancies or gaps in the available information. The study uncovered that estimations of HBW in Iran rely on outdated data, emphasizing their lack of reliability. Several researchers have expressed legitimate concerns about the reliability of FLW data [3,11,13,14], underscoring the need for ongoing FLW measurement and continuous evaluation of data reliability. The survey's results addressed a part of the existing data gap related to HFW in Iran and enhanced the availability of reliable primary data.

The implemented three-layer sampling strategy in the second survey was instrumental in achieving a representative sample and mitigating bias. Researchers have collectively suggested that representativeness in population studies can be ensured through the use of appropriate sampling strategies [15–18]. Omair [15] offers valuable insights into the sample selection process, highlighting the importance of choosing a representative sample. The author suggests employing various probability sampling techniques, such as simple random sampling, systematic random sampling, stratified random sampling, cluster sampling, and multistage sampling, to ensure the sample's representativeness.

During the second survey, by utilizing stratified sampling in the first instance, the selection of samples was distributed across the ten municipal districts of Shiraz, accounting for the population weight of each district based on the number of households. This approach helped ensure that the sample adequately represented the geographical distribution of the city. Stratified sampling is a sampling technique that can guarantee the representativeness of the sample by dividing the population into distinct groups and selecting samples from each group [19–21].

Moreover, the utilization of the most recent national census data as a reference enhanced the precision of the sampling process. Davis et al. [17] emphasize the significance of obtaining a substantial sample that accurately represents the larger population. By employing Daniel's equation [22] for sample size calculation and selecting a reasonable margin of error (5%) while incorporating a 10% buffer to accommodate potential data loss, a reasonable level of representativeness of the surveyed households in relation to the overall target population was ensured. Omair [15] also underscores the significance of taking into account factors such as the size of the study population, confidence level, expected proportion of the outcome variable, and desired precision when determining the appropriate sample size.

Furthermore, the implementation of cluster sampling in the second survey has been beneficial for the inclusion of diverse households within each district. The survey ensured a higher probability of capturing households with different socioeconomic and demographic backgrounds by dividing the districts into square blocks and randomly selecting clusters from residential areas. This sampling approach accounted for potential variations in bread waste patterns and other variables across clusters within the same district. Cluster sampling is widely used in population studies to obtain representative samples. Morris and Nguyen [23] emphasize its applicability in studies where data collection is expensive, time-consuming, or impractical. Therefore, in the second survey, it was determined that utilizing random sampling within each stratum may not have been the most suitable approach. One reason for this decision was the potential for unequal representation of certain characteristics or subgroups in the population, which could introduce bias and compromise the overall representativeness of the sample.

The systematic selection of target households within each cluster contributed to the representativeness of the data. By following a systematic sampling approach, starting from a specific point and spirally approaching neighboring houses, a comprehensive and evenly distributed representation of households within each cluster was achieved. The systematic selection method ensured the inclusion of every third house, minimizing biases related to the household selection. In cases where households were unavailable or unwilling to participate, a predetermined approach of approaching the fifth household forward and backward was employed. This technique further minimized potential bias caused by non-response rates, as alternative households were systematically approached as substitutes. Rehm et al. [16] discuss biases that can arise from excluding sub-populations from the sampling frame and non-response bias. They propose using sampling methods that combine probabilistic sampling with other methodologies to address these biases. This recommendation was considered in the study design and execution of the second survey.

Overall, the careful implementation of this three-layer sampling strategy ensured the representativeness of the data by accounting for geographical distribution, diversity within districts, and systematic selection of households. The strategy minimized potential biases and enhanced the reliability and validity of the findings, making the survey outcomes more robust and generalizable to the population of interest.

The second survey, as discussed in Chapter 6, utilized data analysis and statistical modeling to reveal significant insights into the household-level factors that influence bread waste. This provided valuable information on the behavioral, socioeconomic, and cultural aspects that contribute to this phenomenon. By accomplishing this, it successfully met Research Objectives 5 and 6. Several studies have highlighted the significance of understanding such factors to effectively address food waste. For instance, Ananda et al. [24] found that household behaviors, such as meal planning and storage practices, play a significant role in food waste generation. Similarly, Koivupuro et al. [25] identified socioeconomic factors, such as income level and household size, as important determinants of food waste patterns. Their findings were in line with another study in Denmark and Spain by Grasso et al. [26]. Furthermore, other researchers [27–29] emphasized the influence of cultural norms and attitudes toward food waste on household behaviors. The findings of these studies align with the outcomes of the second survey, highlighting the multifaceted nature of bread waste and the importance of considering various factors when developing strategies to reduce it.

Studying the relationship between household dietary patterns and socioeconomic status with bread waste is crucial for several reasons. Firstly, bread is a staple food consumed worldwide, and significant amounts of it are wasted annually. Annually, more than 100 million tons of bread are produced worldwide, with a total consumption of 129 million tons in 2016 [30]. Around 10% (equivalent to 900,000 tons) of bread is lost during the entire supply chain, spanning from the production stage to consumer consumption [31]. Understanding how households' dietary patterns and socioeconomic status influence bread waste can help identify the underlying factors contributing to this issue. Recognizing the fundamental importance of bread as a food item, unraveling these dynamics holds the key to developing targeted interventions, policies, and initiatives aimed at minimizing bread waste, safeguarding precious resources, reducing environmental impact, and enhancing food security.

Secondly, socioeconomic status often determines access to resources and influences consumption patterns. Khalid et al. [32] discovered that households in Northern Punjab, Pakistan, experience shifts in their consumption patterns toward cultural goods due to education and occupation-based mobility. Similarly, Bock et al. [33] revealed that individuals with a lower perception of economic well-being had reduced motivation to consume for status, with education playing a positive moderating role in this relationship. By studying the relationship between socioeconomic status and bread waste, policymakers and researchers can gain insights into the disparities in food waste and implement targeted interventions to reduce waste and promote more sustainable consumption practices.

Additionally, investigating the relationship between dietary patterns and bread waste, with a particular focus on the health aspects of community nutrition, can provide valuable insights into how cultural and social norms, preferences, and knowledge shape consumption behavior. According to Springmann et al. [34], it is possible to achieve simultaneous improvements in both environmental and health impacts globally through the promotion of healthy eating habits. Smitasiri [35] highlights the significance of community engagement and the efficient mobilization of social resources in advancing sustainable dietary practices. These findings align well with the results of the current study, underscoring the significance of simultaneously promoting healthy diets while addressing environmental and sustainability concerns such as food waste. Understanding these dynamics is crucial for developing targeted educational campaigns and policy interventions that effectively cater to the diverse needs and characteristics of different consumer groups while promoting healthy and sustainable eating habits.

In conclusion, the methodological approach employed in this doctoral research has effectively addressed all six research objectives. Through careful design, comprehensive data collection, and rigorous analysis, valuable insights into wheat loss, bread waste, and their underlying factors have been obtained. By examining the research objectives from various perspectives and employing robust methodologies, this study not only contributes to the existing body of knowledge but also provides valuable findings to derive recommendations and policy advice. Furthermore, it establishes a solid foundation for future investigations in the field of food waste and sustainable consumption. The following section provides a comprehensive discussion of the findings in a broader context, emphasizing their relevance to research in the field, policy development, and intervention strategies.

3. Limitations of the Study and Consideration for Future Investigations

The study was subject to a number of limitations and challenges, which can be classified into two distinct categories: operational and methodological.

One operational limitation faced by the study was the challenging process of obtaining legal permissions in Iran due to political constraints and restrictions by the intelligence service. Such limitations can compromise the ability to conduct unbiased research and access transparent information. The difficulties encountered, particularly during the second survey, including temporary arrests and interrogation of interviewers, despite obtaining permission from multiple authorities, further hindered the smooth execution of the study.

Furthermore, mobilizing and managing a relatively large number of interviewers posed operational challenges due to the scale of the study. Coordinating the efforts of multiple interviewers, ensuring consistent data collection protocols, and addressing logistical considerations required careful planning and allocation of resources. This limitation highlights the importance of effective project management strategies in large-scale research endeavors.

Another operational limitation arose from the restricted access to the necessary existing data for the study. The lack of transparency and reluctance of authorities to share information limited the availability of relevant data, which had implications for the study’s design and analysis. This limitation underscores the importance of enhancing data-sharing practices and promoting transparency in research settings. Furthermore, it partly led to a methodological limitation.

This methodological limitation was the absence of quantitative data in the first survey, as discussed in detail in Chapter 2. The lack of quantitative information limited the ability to conduct robust statistical analysis and obtain comprehensive insights into the research topic. This limitation emphasizes the need for a balanced approach that combines qualitative and quantitative methods to gain a more comprehensive understanding of the subject matter.

The waste quantification method used in the study had limitations and resulted in an underestimation of bread waste quantities. This methodological drawback raises the importance of exploring alternative measurement methods that can provide more accurate and reliable waste estimates. Future research should consider employing a combination of techniques to improve the accuracy of waste quantification. This limitation has been thoroughly discussed in Chapters 4 and 5.

Moreover, the use of lab measurement for assessing waste may not be as effective in other study cases or for different food commodities, as elaborated in Chapter 4. This methodological limitation highlights the need for considering context-specific measurement approaches that align with the nature and characteristics of the studied food items. Researchers should be cautious in generalizing findings based on specific measurement methods and consider the contexts in which they are applied.

Another methodological limitation of the study relates to the measurement of bread waste. The study utilized the percentage of the mass of purchased bread in households as an indicator of waste. While this approach provides insights into the quantity of wasted bread, it does not account for the potential variation in the economic value of different bread products. Traditional methods of measuring FLW, which rely on physical units like tonnes, may prioritize low-value products solely based on weight. In order to address this limitation, future research should consider incorporating economic valuation methods that capture the monetary costs and benefits associated with bread waste. To address the need for a comprehensive measurement approach, the Food and Agriculture Organization (FAO) [36] and the United Nations Environment Programme (UNEP) [37] have introduced the Food Loss Index (FLI) and the Food Waste Index (FWI), which take into consideration the economic value of different commodities, providing more accurate assessments of progress toward SDG Target 12.3. By adopting these indices in future studies on FLW, interventions and policies aimed at reducing bread waste can be better informed and targeted.

One limitation of the study on HFW was its narrow focus on examining only one specific food item, namely bread. However, bread holds significant importance as a key ingredient in typical diets worldwide. While the findings of the study provided valuable insights, it is important to acknowledge that the results may have differed if other food items or groups were included in the analysis. While it is understandable to focus on a single food item when studying loss and waste in other segments of the food supply chain (FSC), conducting a household study would benefit from including a wider range of food items.

Finally, collecting dietary data primarily from mothers or wives in households assumes that their dietary intake reflects the overall dietary status of the household. While this assumption is supported by the literature [38–42], there is still a possibility of bias in the data collected. Researchers should be mindful of this potential bias and consider incorporating additional perspectives and sources of dietary information to ensure a more comprehensive assessment of household dietary patterns.

Acknowledging and addressing these limitations provides a clearer understanding of the study's scope and potential implications for interpreting findings. It also highlights areas for improvement in future research endeavors and encourages a more nuanced and comprehensive approach to studying the subject matter.

4. Implications of Major Findings and Directions for Future Research

This section expands on the findings of the present doctoral study and explores their broader implications. The three subchapters within this section focus on key areas of research within this doctoral study and propose directions for future investigations.

4.1. Wheat and Bread Lifecycle and Availability of Data

The findings on the WBL, extensively presented and discussed in Chapter 2, provide a comprehensive understanding of the dynamics and the interrelation of different actors within the WBL in the Fars region. These findings shed light on specific areas where loss and waste are most prevalent, highlighting the need for further data collection to fill existing gaps. The approach employed in Chapter 2 offers a valuable framework that can be adapted and applied in future studies examining the loss and waste of various food commodities and groups. The insights obtained from this research contribute to the broader knowledge base and offer valuable guidance for addressing FLW in a more holistic and systematic manner, as they encompass critical stages of the food lifecycle, spanning from breeding institutions to farms, and from farms to consumers, extending further to encompass landfill and food recycling processes.

Adopting a holistic and systematic approach is crucial when studying and addressing FLW, as well as developing effective interventions and strategies for their reduction. It is crucial to acknowledge that the production of FLW is an inherent characteristic of the structure of the FSC [43]. Previous research has indicated that focusing solely on specific stages of the supply chain is insufficient, as reductions in losses at one stage may be accompanied by increases at others [44]. Therefore, a comprehensive examination of the entire supply chain is necessary. Magalhães et al. [45] further emphasize the need to address the root causes of FLW, which are prevalent across various stages of the FSC. They suggested that to tackle this challenge, the involvement of multidisciplinary teams is recommended to develop holistic solutions for preventing and mitigating FLW.

Some of the benefits of the lifecycle approach utilized in the present study are outlined in Chapter 2. These include aligning the definitions of FLW with international organizations like the FAO and the UNEP to enhance progress monitoring toward SDG 12.3 and improve data comparability across studies. Additionally, the approach enables effective identification and targeting of hotspots for loss and waste, provision of educational resources for industry practitioners, and support for lifecycle assessment (LCA) and circular economy studies. However, the findings related to the mapping of the WBL offer additional advantages to consider, as elaborated below.

The accurate portrayal of the WBL recognizes its inherent complexity. The comprehensive understanding gained from this research can serve as a foundation for future studies, facilitating further investigations into loss and waste within the WBL and potentially extending to other food commodities. The findings have significant implications for policymakers and practitioners in Iran, providing valuable insights for the supply chain management of wheat and bread. This includes identifying specific loss and waste hotspots and areas that demand additional attention. These outcomes can contribute not only to reducing loss and waste but also to enhancing overall productivity and efficiency within the WBL.

The farm-to-fork approach in supply chain management offers multiple benefits beyond increased productivity, including improved food safety and quality assurance through enhanced traceability [46]. Moreover, the holistic overview of the WBL presented in the current study allows for a broader perspective beyond the traditional farm-to-fork approach, encompassing other lifecycle stages, such as breeding, landfills, and animal farms. Lavelli [47] emphasizes the importance of adopting a holistic research approach that combines value-addition strategies with risk analysis, forecasting, and optimization studies throughout the entire FSC. This approach takes into account various challenges, including food contamination and loss. Furthermore, deploying information technologies such as the Internet of Things (IoT), when coupled with a comprehensive understanding of the entire food lifecycle, can promote transparency, interconnectivity, and effectiveness in managing a circular FSC [47].

The mapping approach employed in this study had broad implications as it acknowledged the structural and complexity variations among supply chains and lifecycles of different commodities, despite the common linear farm-to-fork structure. Several studies provided valuable insights into these differences across various types of FSCs. Carbone [48,49] extensively discussed the coordination modes (vertical and horizontal) and governance structures within different chains, highlighting the advantages and limitations associated with delivering spot-specific quality that could impact production efficiency. King et al. [50] focused on local FSCs and their business models, emphasizing how different structures influenced producers' management of high, fixed costs across multiple revenue streams. Similarly, studies on FLW confirmed that the characteristics of different supply chains, including transportation, packaging, storage, harvest-to-sale time and path, and selling channels, varied significantly across food commodities, leading to distinct impacts on FLW [45,51,52]. Failing to understand the specificities of different FSCs could result in confusion and hinder the establishment of circularity in food systems and practical FLW mitigation efforts [53]. This disadvantage can be tackled by adopting a tailored and context-specific approach to mapping and analyzing the unique characteristics of each FSC, which would provide a more accurate understanding of the dynamics between different actors involved and facilitate targeted interventions for improving sustainability and reducing waste.

This study also emphasized the need for data availability, which aligns with previous research indicating a significant lack of data that hampers the evaluation of the status of FLW and the monitoring of progress toward SDG 12.3 [11,14,54,55]. Multiple researchers have highlighted the importance of ongoing measurement of FLW [11,14,54,55]. The study also reveals that although input and output data are recorded at most stages of the WBL, responsible organizations fail to utilize this data effectively for reporting loss and waste. This is likely the case in many other countries, as missing data is common in less developed countries. According to the UNEP [37], Reliable data on food waste at consumption stages are mostly limited to developed countries. Xue et al. [11] found that existing publications on FLW primarily focus on a few industrialized countries. Other examples may include the scarcity of data on food waste found in the Western Balkans [56], a paucity of applied studies on FLW exists in the Arab world [4], and the lack of adequate research to collect FLW data in Latin American countries [57].

Therefore, it is crucial to conduct more studies that quantify the FLW at different stages of food lifecycles. Additionally, there is a need for political will to encourage responsible authorities to utilize existing material flow data for measuring and reporting FLW. Transparency in FSCs plays a vital role in achieving this goal, as it allows for better monitoring and tracking of food flows. Leveraging digitalization can be a key enabler in increasing transparency within the FSCs, facilitating real-time data sharing, and improving traceability [58,59]. The digitalization of FSCs provides stakeholders with timely and accurate information, enabling them to make informed decisions, optimize operations, reduce waste, and improve the overall sustainability of the FSC [60,61].

Digital technologies enable stakeholders to identify inefficiencies and areas for improvement, leading to more effective management of FLW. In recent years, a growing body of research has focused on the digitalization of FSCs and its potential benefits for reducing FLW. Hook and Soma [62] found that digital agricultural tools, such as farm management apps, can enable farmers to accurately document their yield and sales, providing a valuable means of quantifying food loss. Vieira et al. [63] revealed that Digital Business Platforms (DBP) could contribute to food waste solutions by enhancing coordination within the supply chain and creating new markets for food that would otherwise be discarded. Annosi et al. [64] highlight the potential of big-data management solutions to foster collaboration across the FSC and improve overall business performance, although barriers to diffusion still exist. Moreover, Benyam et al. [65] emphasize that the adoption of digital agricultural technologies has the potential to prevent or reduce FLW, but challenges such as high investment costs and the digital divide among technology adopters limit widespread implementation.

Utilizing blockchain technology in FSC management has recently emerged as a subject of growing interest among researchers. A blockchain refers to a distributed digital ledger that securely records information transactions across a network of interconnected computers [66]. It operates using encryption models that make it almost impossible to tamper with the data once entered into the distributed ledger [67]. The key characteristics of blockchain include decentralization, transparency, security, and immutability [68].

Blockchain technology has the potential to enhance transparency and traceability in the FSC, thereby aiding in the prevention of FLW [69,70]. Machado et al. [71] propose that blockchain can be leveraged for managing scientific research projects involving food products, increasing confidence in the validity of research outcomes. Duan et al. [72] suggest that blockchain can improve food traceability, information transparency, and recall efficiency by providing an immutable and transparent record of each transaction, ensuring data integrity, and facilitating rapid identification and retrieval of relevant information in case of product recalls or quality issues.

However, these studies also recognize the obstacles and limitations associated with the implementation of blockchain in the FSC. According to Mohammed et al. [73], the main obstacles to the implementation of blockchain in FSCs are scalability, interoperability, high costs, lack of expertise, and regulatory constraints. Katsikouli et al. [74] state that the widespread adoption of blockchain technology in the FSC still requires developing regulations and improving the understanding of the technology. Moreover, Rogerson and Parry [75] point out remaining challenges in areas such as lack of trust in the technology, the potential for human error and fraud, and ensuring consumer data accessibility and willingness to pay. Nevertheless, emerging evidence suggests that blockchain technology holds promise for improving efficiency and transparency in FSC management, leading to better availability of FLW data. Therefore, future research should delve into examining the advantages and disadvantages of utilizing blockchain or other advanced technologies in FSC management and exploring its potential benefits for reducing FLW.

4.2. On-Farm Loss and Role of Agricultural Cooperatives

As presented in Chapter 3, the second peer-reviewed article examined on-farm loss through a qualitative approach. The study conducted in-depth interviews to gain insights into the primary production of wheat and identified key areas where losses occur. Findings revealed that seed overuse, pest infestation, and improper harvesting were prominent factors contributing to wheat loss. The article delves into the underlying factors associated with these primary causes and emphasizes their negative effects on the environment, economy, and society. Additionally, the article explores potential approaches to address this issue and proposes empowering agricultural cooperatives through changes in government engagement in wheat production.

Utilizing a qualitative approach in the study allowed for a comprehensive examination of the causal relationship between farming practices and on-farm food loss while shedding light on other essential sustainability aspects. This approach aligns with the practices of other researchers who have recognized the strengths of qualitative methods in studying on-farm loss. Gascón et al. [1] contend that qualitative approaches can lead to the development of more effective solutions for mitigating on-farm loss, surpassing the sole quantification of loss amounts. Beausang et al. [76] conducted semi-structured interviews with fruit and vegetable farmers in Scotland, revealing that farmers do not consider food waste a primary concern and perceive it as inherent to farming. Similarly, Campbell [77] conducted a pilot study in California, identifying market volatility and unpredictable weather as key contributors to on-farm food loss. Similarly, the present study identified the underlying reasons for significant wheat loss occurrences on farms through in-depth qualitative analysis of interviews with experts and practitioners.

However, the importance of quantitative studies in understanding on-farm food loss cannot be emphasized enough, as highlighted by the FAO [36] and UNEP [37]. Several studies have utilized quantitative methods to measure food loss and examine its variation based on different factors. Examples include Esgici et al. [78] and Hofman and Kucera [79], who employed statistical analysis to determine how harvest loss differs depending on machinery use and technical setups. Quantitative measurement of loss not only aids in understanding the magnitude of the issue but also assists in finding solutions that correspond to the severity of loss. Therefore, further studies need to employ a combination of quantitative and qualitative methods to explore the underlying causes of loss, assess its magnitude, and examine its relationship with other factors. This approach can be regarded as a logical follow-up of the present study.

The article also explored strategies to address wheat loss, with particular attention to the role of agricultural cooperatives. The findings of this article have significant implications in a broader context, extending beyond the specific geographic and social context of the study. These implications revolve around several key areas, including environmental sustainability, food security, socioeconomic development, and policymaking. The insights provided shed light on the causes and consequences of wheat loss on farms and offer potential solutions to tackle these challenges. By addressing the underlying issues contributing to the wheat loss, these findings contribute to enhancing environmental sustainability in agriculture, ensuring food security, fostering socioeconomic progress, and informing policy formulation.

Firstly, the findings emphasize the environmental implications of on-farm wheat loss. The long-term intensive cultivation of cash crops, including wheat, maize, and rice, has resulted in reduced production efficiency and farming challenges, leading to excessive seed use and difficulties in pest control. These factors not only contribute to food loss but also pose threats to biodiversity and soil fertility. The outcomes of this study reaffirm the well-established knowledge regarding the adverse environmental consequences associated with inefficient farming practices, aligning with previous research findings [80–82]. However, in order to develop effective and context-specific solutions, it is crucial to evaluate the environmental impacts and their underlying causes within specific societal and geographical contexts [83–85]. Therefore, as an initial step, prioritizing the comprehensive evaluation of the current environmental impacts of farming practices becomes imperative in order to gain a thorough understanding of the extent of the issue and inform targeted interventions.

The study underscores the urgent need for a transition toward sustainable and ecological farming practices, such as diversified rotational cropping and ecological pest management, in order to mitigate the environmental risks highlighted in the findings, such as loss of biodiversity and soil fertility. These insights hold significance not only for the stakeholders in the study region but also for other regions within Iran and countries that may not prioritize environmental preservation. It is crucial to recognize that there are likely other countries facing similar challenges, where an immediate and pivotal shift in farming practices is required to regenerate lost biodiversity and soil fertility resulting from the intensive cultivation of cash crops [86]. Dios-Palomares et al. [87] emphasize the importance of assessing the environmental efficiency of farming systems and embracing transformative changes toward more environmentally friendly practices, particularly in Latin America and the Caribbean. Additionally, Balsalobre-Lorente et al. [88] identified the significant environmental impacts associated with agricultural activities in BRICS countries, highlighting the need for sustainable practices alongside energy use and trade openness. The outcomes of the present study reiterate the pressing need to move away from intensive farming and the exploitation of natural resources toward more sustainable and environmentally friendly approaches. Future research should focus on developing context-specific solutions and innovative farming systems that preserve biodiversity and soil fertility while simultaneously meeting the increasing nutritional demands of the population.

Secondly, the implications extend to food security. The significant losses in wheat production observed in the study have direct implications for local and regional food availability. Addressing on-farm losses and improving production efficiency is crucial for enhancing food security in the Fars region and beyond. The findings of the study align with previous research. Sawaya [89] emphasizes the significant challenge posed by FLW, particularly in regions where a considerable number of people suffer from chronic undernourishment. Kuiper and Cui [90] identified promising leverage points for reducing food loss from a food system perspective, highlighting that the most significant impacts on food security are observed in low-income regions. Lastly, Rutten and Kavallari [91] argue that focusing on reducing food losses in the

Middle East and North Africa region is more beneficial for promoting agricultural growth than relying on manufacturing and service-led growth. This approach has positive effects on food security by reducing dependence on and vulnerability to changes in the global food market and improving the living conditions of rural communities [91]. Similarly, the present study's recommendations, such as optimizing equipment, providing financial support, and offering training opportunities, can contribute to reducing harvest losses, ensuring a more reliable food supply, and reducing dependence on imports and the global market.

Thirdly, the socioeconomic implications are noteworthy. On-farm losses result in significant financial losses for farmers, affecting their livelihoods and economic well-being. Previous studies have underscored the significance of evaluating and mitigating the socioeconomic consequences of on-farm food loss. Willersinn et al. [92] discovered that reducing potato on-farm loss can enhance the socioeconomic performance of the entire supply chain. Agarwal [93] highlights how post-harvest losses lead to food insecurity, elevated food prices, and the depletion of scarce resources utilized in production. Gillman et al. [94] state that on-farm losses occur as a result of attempts to manage economic risk within FSCs, and suggest that these losses can serve as a preventive measure against more environmentally damaging "waste" later in the chain. However, the relationship between FLW reduction and food security is intricate, and positive outcomes are not always guaranteed.

Balancing the advantages and disadvantages of FLW reduction, as discussed in the current study and by other researchers, achieving optimal levels of food and nutrition security necessitates a certain degree of FLW. The need to maintain food reserves for stability inevitably leads to a certain amount of loss or waste [36]. Simultaneously, ensuring food safety requires the disposal of unsafe food, which is classified as FLW, while higher-quality diets often include more perishable food items [36]. Moreover, the economic viability of reducing food loss is not always straightforward [95]. The assessment of costs associated with implementing FLW reduction strategies has received limited attention [96]. The expenses involved in these strategies can sometimes outweigh their economic advantages compared to alternative solutions [97]. Therefore, finding a balance between economically sound practices and minimizing loss and waste is crucial. Future efforts should focus on context-specific solutions to mitigate the socioeconomic impacts of on-farm food loss while carefully considering the economic costs associated with reducing FLW and the objective of minimizing FLW to the greatest extent possible.

In the present study, the comprehensive exploration of the role of agricultural cooperatives in mitigating on-farm food loss and enhancing agricultural productivity offers valuable insights for future research. The implementation of recommended strategies, such as promoting cooperative actions and providing support for farmers, has the potential to foster agricultural productivity, create income opportunities, and improve the socioeconomic conditions of farming communities. Previous studies have explored the impact of cooperatives on agricultural development in different contexts. For instance, James and Joshua [98] observed the positive effects of farmers' cooperatives in Nigeria, particularly in income generation, collective experience, agricultural activities, and leadership quality. Gebremichael [99] highlights the contributions of agricultural cooperatives in Ethiopia to food security and women's empowerment through access to inputs, credit, output markets, and diversified crop production. Giannakas and Fulton [100] developed a game theoretic model demonstrating that cooperative involvement in process innovation can lead to increased productivity growth and reduced input prices.

However, the role of agricultural cooperatives, specifically in reducing on-farm food loss, remains largely unexplored. The present study emphasizes the significance of collective cooperation and knowledge-sharing through cooperatives to effectively address on-farm food loss and inefficiencies. Future studies should aim to further explore how cooperatives can contribute to mitigating on-farm loss in diverse socioeconomic and geographic contexts while also considering different types of food items. In this context, it is essential to highlight the specific attributes of cooperation and their positive impacts. These attributes include collaborative decision-making, resource pooling, shared learning, economies of scale, enhanced access to markets, and improved bargaining power [101]. By illuminating these aspects, future research can provide valuable insights for policymakers, practitioners, and stakeholders seeking to harness the potential of agricultural cooperatives in addressing on-farm food loss effectively.

Finally, the findings of this study have significant implications for policymaking and intervention strategies. It highlights the importance of supportive government policies that facilitate sustainable farming practices, provide financial assistance, foster a competitive market, reduce centralized control, and strengthen democratic decision-making processes for agricultural cooperatives. Campbell et al. [77] and Gillman et al. [94] emphasize the multifaceted nature of on-farm food loss, which is influenced by various factors beyond farmers' control. They argue that current agricultural policies hinder the effective reduction of food loss by not adequately aligning efforts with the limitations and needs of farmers. Therefore, it is crucial for governments to take on a supportive role, encompassing initiatives such as providing cooperatives with access to education and financial resources, nurturing a vibrant and competitive market structure, reducing undue centralization and external interference, and empowering cooperatives through democratic decision-making processes and enhanced freedom. Implementing these policy measures can create an enabling environment for reducing food loss, promoting sustainable agriculture, and enhancing the overall efficiency and effectiveness of the FSC.

In a broader context, the outcomes of this study offer valuable insights for researchers, practitioners, and policymakers worldwide. The challenges and solutions identified in the Fars province can be extrapolated to other regions and countries experiencing similar issues in agricultural production, food loss, and food security. The study's emphasis on the importance of adopting a comprehensive approach that combines qualitative and quantitative methods provides a framework for future research and policy interventions to tackle food loss, enhance farming practices, and promote sustainable agricultural development on a global scale.

4.3. Household Food Waste

The outcomes of the household survey are presented across three distinct areas, which have been detailed in separate articles within Chapters 4 to 6. These areas encompass the improvement of household waste quantification methods, the measurement of HFW amounts, and the exploration of underlying factors linked to HFW. Each area provides valuable insights and findings that contribute to a broader understanding of the issue. In the following, a more comprehensive understanding of HFW and its various dimensions is provided through a collective discussion of the three areas.

4.3.1. Improvement of Household Food Waste Quantification Methods

The study's findings on household waste quantification methods in the present doctoral research underscore the significance of accurately measuring domestic food waste. Previous studies have highlighted the necessity of precise measurement of HFW to guide policymaking and achieve waste reduction goals [102–104]. Currently, two primary methods are employed: direct measurements and self-assessments or self-reports. However, both approaches have their limitations. While direct measurements offer accuracy, they can be impractical due to high costs and labor requirements [105]. Conversely, self-assessments, although practical, are susceptible to uncertainty in waste measurement [11,104,106,107]. In order to address this issue, the study proposes an innovative approach that mitigates errors in self-assessment methods, striking a balance between the costs of implementation and the reliability of data.

By simulating common bread consumption recipes in the lab, measuring the resulting waste, and calculating the underestimation ratio through statistical comparisons with the self-assessment results, the study compensates for underestimation errors in the employed self-assessment method. Consequently, a more realistic estimation of HBW is provided. This approach serves as inspiration for other researchers to utilize a similar approach that fits their study context, thereby enhancing the reliability of data obtained through self-assessment methods.

This study highlights the potential for enhancing the accuracy of data collection in measuring HFW through innovative approaches, calling for a reevaluation of the traditional methods of direct measurement and self-assessment. Other researchers have also proposed novel techniques that offer more practical and precise ways of quantifying HFW. For instance, van

Herpen and van der Lans [108] introduced a unique estimation method by visually inspecting photographs of food waste and estimating the quantity, which yielded promising results with high accuracy. Their approach builds upon previous studies that utilized photograph coding to estimate food portion amounts, a method proven to be highly reliable [109–112]. By integrating such pioneering methods with advanced digital technologies, a paradigm shift in measuring HFW becomes possible, leading to improved efficiency and accuracy in data collection.

Recent studies have recognized the effectiveness of digital technologies, such as the use of image recognition, in recognizing, classifying, and quantifying food materials. Guo et al. [113] employed an algorithm model based on the EfficientNet deep learning convolutional neural network to recognize and classify household garbage. The EfficientNet architecture is specifically designed to achieve high accuracy in image classification tasks while also maintaining efficiency in terms of parameter count and computational resources required [114]. Additionally, Nagaraju and Shubhamangala [115] explored the capabilities of AI image recognition in classifying and quantifying domestic food waste. Their findings demonstrated the powerful nature of Convolutional Neural Network (CNN) models in accurately quantifying food waste through image recognition. CNNs are a type of deep learning model optimized for processing structured grid-like data, such as images or sequences [116]. Similarly, Lubura et al. [117] investigated the use of CNNs to recognize food images before and after meals and estimate the percentage of food waste, achieving an impressive accuracy of 0.988. These studies underscore the promising potential of digital technologies in enhancing the accuracy of data collection for food waste. Consequently, interdisciplinary efforts are vital in developing practical and precise methods for quantifying HFW, facilitating continuous measurement and monitoring of such waste.

Increasing the availability of HFW data requires the active involvement of consumers. According to Pateman [12], citizen science, which involves public participation in collecting data and engaging in scientific processes, plays a vital role in measuring and comprehending the factors contributing to FLW. In order to achieve this, it is essential to provide domestic consumers with user-friendly tools for measuring food waste and to make the collected data accessible to researchers and policymakers.

Mobile applications are particularly suitable for this purpose. Farr-Wharton [118] examines three mobile applications—Fridge Pal, LeftoverSwap, and EatChaFood—that have the potential to minimize HFW by enhancing consumer awareness of food availability, location, and understanding. Furthermore, Liegeard and Manning [119] propose that intelligent applications such as smart packaging and appliances have the capability to tackle food waste while empowering individuals to enhance the storage conditions of products and reduce waste. However, none of these applications currently incorporate a measurement option to enhance data availability on HFW. Therefore, future research should prioritize developing mobile applications that utilize digital technologies, as mentioned above, to not only help reduce HFW but also improve the availability of data for monitoring progress in HFW reduction efforts.

4.3.2. Household Food Waste Amount

The study outlined in Chapter 5 addresses a significant data gap by estimating the HBW amount in Shiraz. This research is particularly valuable because there has been limited investigation into this specific topic in Iran [120,121]. Furthermore, given the widespread consumption of bread as a staple food by millions of individuals [122], the outcomes of this study have implications beyond the Fars region. The findings can serve as a reference point for comparing results in different geographical and socioeconomic contexts. As such, this study not only contributes to the existing knowledge base but also provides insights that can be utilized in future research to enhance our understanding of HFW and its broader implications. In this regard, the implementation of an overarching standardized procedure could facilitate inter-regional comparisons.

This study makes a significant contribution to addressing the general data gaps highlighted by UNEP [37], Xue [11], and Fabi [14]. These sources emphasize the limited availability of food waste data at the household level in developing countries, which has hindered efforts to comprehensively understand the scale of food waste and monitor progress toward SDG 12.3. Obtaining accurate and up-to-date data is the key to establishing practical FLW reduction strategies and monitoring their progress [95,123]. By focusing on household-level food waste in the context of a developing country, this study effectively fills the data gap and provides valuable insights into the severity of food waste. Although the study’s contribution may be modest, it represents a significant step forward in advancing our understanding of food waste and closing the knowledge gap.

The distinct focus of the study on bread allowed for a comprehensive understanding of the extent of bread waste. This approach is supported by Willersinn [124], who studied potato waste in the Swiss FSC and emphasized the importance of focusing on a single food item to gain a deeper understanding of the issue. A notable example is the research conducted by Doluschitz et al. [125], which focused on the role of information technologies in tracing and ensuring the quality of food from animal sources. This study suggests that optimized data collection and information management can be achieved by focusing on individual animals [125]. However, it should be noted, as discussed in the limitations section, that studying more than one food item would provide valuable insights for identifying effective food waste reduction solutions. Therefore, future HFW studies should aim to incorporate at least one food item from each of the six food groups outlined by FAO [126], which include cereals, oilseeds, root crops, fruits and vegetables, meat and dairy products, and fish.

Adopting this broader approach is particularly crucial for the development of digital HFW measurement tools that were discussed earlier. By incorporating multiple food items from different essential food categories, these tools can provide a more comprehensive and accurate assessment of HFW. This broader approach will enable researchers and developers to create digital tools that cater to a wider range of food waste scenarios, capturing the diversity of food items and consumption patterns. In this context, including food groups with high amounts of domestic waste, such as fruits and vegetables [127], or food items with high economic value and larger environmental footprints, such as meat products [128], is particularly important. The inclusion of a wider range of food items will facilitate the identification of common trends and patterns across different food groups, leading to more effective strategies for food waste reduction.

4.3.3. Underlying Factors Linked to Household Food Waste

The research study has yielded several key findings that have important implications for understanding and addressing the issue of bread waste and its associated factors. Firstly, the study revealed a significant correlation between household dietary patterns and bread waste, which was in line with two similar studies in the US [129] and Canada [38]. This finding suggests that promoting healthier eating habits and education about nutrition can potentially reduce bread waste at the household level. Implementing targeted educational campaigns and interventions that emphasize the health benefits of balanced diets and mindful consumption can contribute to both the reduction of food waste and the improvement of overall health outcomes.

Secondly, the research highlighted the influence of socioeconomic factors on bread waste. The study found that households with lower socioeconomic status tend to have higher levels of bread waste. The findings of this study align well with other research conducted in the field. In a study in Uruguay, Aschemann-Witzel et al. [130] demonstrated that higher socioeconomic groups tend to waste fresh produce more frequently due to sub-optimal practices, suggesting a potential increase in avoidable food waste with increasing affluence. Monavari's 2012 study [131] in Iran revealed a connection between household solid waste generation and variables such as family size, education level, and household income. Similarly, Koivupuro et al. [25] identified multiple factors that influence the amount of avoidable food waste in households in Finland, including household size, the gender of the primary grocery shopper, frequency of purchasing discounted food items, and individuals' own perceptions of their ability to reduce food waste. Stancu et al. [132] also indicated that food waste was driven by perceived behavioral control, routines related to shopping and reusing leftovers, and planning habits, all of which were associated with consumers' perceived capabilities in managing household activities.

These collective findings indicate the need for strategies that address food accessibility and affordability for different segments of communities. Such studies contribute to the understanding of the complex dynamics influencing food waste. Implementing policies and initiatives that aim to improve economic conditions, increase access to affordable and nutritious food options, and promote food waste reduction practices can help alleviate the burden of bread waste on vulnerable populations.

Furthermore, the present study highlighted the importance of cultural norms and preferences in shaping bread waste behaviors. These findings are in good agreement with previous research. Apolonio et al. [29] emphasize the role of social norms, such as attitudes toward food conservation and acceptance of expiration date-based pricing, in determining food waste generation. Similarly, Mattar et al. [27] found that beliefs, such as feelings of guilt, had a decreasing effect on food waste, while behaviors such as frequent dining out and purchasing based on the best offers increased food wastage. A study by Hebrok and Boks [133] identified socio-cultural and material factors as significant drivers of food waste and emphasized the need for further investigation to test innovative ideas and interventions to reduce HFW. Therefore, it is crucial to consider cultural norms and behaviors when designing policies and societal interventions to address HFW. Tailoring interventions to specific cultural contexts can enhance their effectiveness. Collaborating closely with local communities, involving community leaders, and leveraging existing social networks can facilitate the adoption of sustainable dietary practices and contribute to reducing bread waste.

Figure 2 provides a visual representation of the intricate nature of HFW and its interconnectedness with various factors. This figure is created based on the findings of the current study as well as insights from other relevant studies discussed in Chapter 6. It should be noted that the factors depicted in the figure are not exhaustive, as there may be additional elements influencing HFW. The figure employs red lines to illustrate the interdependencies and interrelations between these factors, emphasizing their intricate nature. By portraying the complexity of HFW, the figure effectively highlights the need to comprehend its multifaceted nature in order to devise effective strategies for its reduction. Understanding the complex dynamics at play, such as the interrelations between the factors influencing HFW, is crucial for developing targeted and comprehensive approaches to tackle HFW.

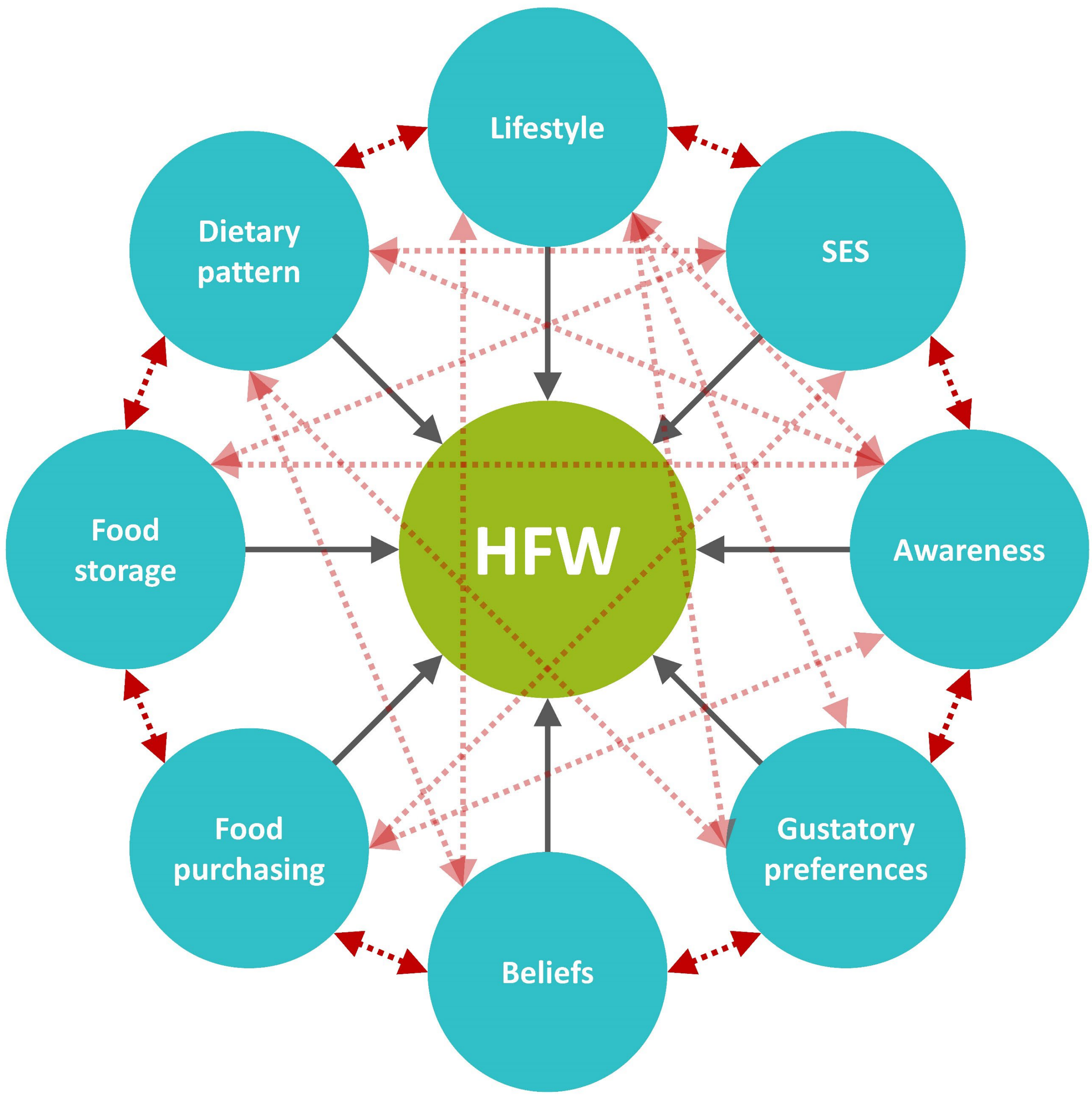

Figure 2. Illustration of the complex interconnections of household food waste with various factors.

In conclusion, the findings of this study offer valuable insights into the intricate connection between dietary patterns, socioeconomic factors, cultural influences, and bread waste, as outlined in Chapter 6. The study underscores the importance of customized food waste reduction strategies that cater to specific population groups, yielding more effective results and progress toward SDG 12.3. These findings have significant implications for the development of targeted interventions and policies that promote healthy eating habits, address socioeconomic inequalities, and account for cultural contexts. Through the implementation of these measures, we can make strides in reducing bread waste, enhancing food security, and fostering more sustainable consumption practices. This can be achieved by first evaluating the extent of HFW and understanding its dynamics with influencing factors in specific contexts and then designing policies and interventions to address the issue in relation to its unique characteristics and attributes.

5. Closing Remarks

In retrospect, the following remarks provide a general overview of the outcomes of the present doctoral study and further considerations regarding the approach to addressing the issue of FLW.

This doctoral study has provided valuable insights and considerations regarding the approach to addressing the issue of FLW. A holistic approach is crucial for studying FLW and designing effective reduction strategies. However, based on the experience gained from this research, it is recommended to adopt a two-fold approach in addressing FLW. Firstly, it is important to separate the household segment from other stages of the food lifecycle, allowing for a more focused analysis of specific food items throughout their entire lifecycle. This approach avoids becoming overly entangled in the complexities of HFW. Secondly, it is recommended to comprehensively study HFW as an individual focal point in the food lifecycle and consider including at least one food item from each of the six major food groups mentioned above. This comprehensive approach will enable a deeper understanding of the complexities surrounding FLW and facilitate the development of targeted interventions and policies.

To comprehensively analyze FLW throughout the entire lifecycle of a food item, it is vital to improving transparency in terms of the structure and dynamics of each lifecycle and data availability concerning material flow and quantities. This approach should encompass all segments of the food lifecycle, including consumption stages such as foodservice, while not necessarily focusing solely on households. As previously discussed, leveraging digital technologies can greatly aid in this endeavor, enhancing overall productivity and improving quality and safety management. Real-time monitoring of loss and waste across all segments enables the timely identification of areas where food is lost or wasted, facilitating targeted interventions to address the issue and enhance the overall efficiency of the supply chain.

When analyzing HFW, it is crucial to include at least one or more food items from each distinct food group. This comprehensive approach ensures a holistic understanding of food waste patterns and behaviors. Given the complex nature of HFW, a multifaceted approach is necessary, involving diverse disciplines and perspectives. Interdisciplinary research plays a significant role in these studies as it enables a comprehensive analysis of the social, economic, cultural, and environmental factors that contribute to food waste. Moreover, it explores the potential of other sciences and technologies in assisting with the reduction of FLW, such as nutrition sciences and digital technologies.

Effective interventions aimed at reducing food waste should also address other aspects, such as promoting dietary health and lifestyle improvements. By considering these additional dimensions, interventions can have a more comprehensive impact on sustainable food consumption. Furthermore, it is important for studies to focus on specific target groups to develop tailor-made strategies that can effectively reduce food waste. Understanding the unique characteristics and behaviors of different groups enables the design of targeted interventions that address their specific challenges and needs, leading to more successful outcomes in food waste reduction efforts.

In conclusion, addressing FLW necessitates collective and interdisciplinary efforts involving various stakeholders in the food industry, policymakers, governmental authorities, and, most importantly, consumers. It is a shared responsibility to reduce FLW throughout the entire FSC. Effective strategies and interventions require collaboration, coordination, and engagement from all parties involved. By working together, we can create a sustainable and efficient food system that minimizes waste, preserves resources, and ensures food security for present and future generations. It is only through collective action that we can make a significant impact and achieve our goals in reducing FLW. A crucial question that needs to be addressed is the identification of the FSC leader in complex supply chains comprising multiple independent enterprises of varying size and influence. In this regard, public authorities play a crucial role as fiduciary institutions, acting as intermediaries between consumers and other stakeholders in the FSC. Their role is to facilitate coordinated and collaborative efforts while considering significant aspects such as environmental sustainability and food security in their policymaking processes, thereby promoting a safe and equitable FSC.

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Additional Scientific Contributions

1. Overview

This chapter provides abstracts of two scientific contributions presented at international conferences. These two proceeding articles were authored within the context of the doctoral study. Although these contributions are relevant to the overall research, they are not considered integral components of the dissertation. These abstracts offer a glimpse into the additional scholarly work undertaken during the course of this doctoral study, demonstrating the breadth and depth of the research conducted beyond the scope of the main dissertation.

2. Proceeding Article 1

Title of the Proceeding Article: Lifecycle Assessment as an Evolving Tool for Evaluating Food Sustainability: Challenges and Opportunities

Authors: Shahin Ghaziani

Presented at: Congress 2019 of the Humanities and Social Sciences, June 1–7, 2019, Vancouver, Canada

Abstract

Lifecycle assessment (LCA) has been widely used for sustainability evaluation of certain phenomena in different fields including food systems. Due to the complex nature of food systems, mainly caused by the strong links with human's well-being, implementing LCA in this context requires particular considerations which distinguish its application from most of the other areas. The present work, which is based on a pilot study for applying LCA on different types of wheat bread, attempts to debate two main challenges and their possible solutions on the way of finding the best LCA practices for investigating the food lifecycles. The first challenge would be how to define the functional unit of a food item. Previous studies used energy delivery as the basis of the functional unit definition. However, our consumption survey revealed that the social and, more particularly, psychological function of different types of a certain food item seems to play an essential role in consumers' satisfaction. The possible solution could be using a combination of major criteria in identifying the functional unit. The second challenge could be how to account for the major factors in LCA modeling. Sustainability relies on achieving the equilibrium between the environment, society, and economics. Yet in most of the food LCA studies, mainly only the environmental impacts of the systems mostly at production and distribution stages of food lifecycles have been accounted for. Therefore, it is vital to include social (e.g. health) and economic data of all stages in the LCA model to achieve holistic evaluation.

3. Proceeding Article 2

Title of the Proceeding Article: Rethinking the Dietary Patterns Towards Reducing Food Loss and Waste to Achieve Sustainability: A Lifecycle Perspective

Authors: Shahin Ghaziani, Reiner Doluschitz

Presented at: The 3rd International and the 15th Iranian Nutrition Congress, December 19, 2018, Tehran, Iran

Abstract

How to feed the growing human population? This is one of the key challenges mankind is facing. Some experts may find the answer in producing more food through agriculture intensification. Nevertheless, more efficient use of the existing food resources is undeniably one of the main possible solutions. This may be achieved by ensuring sustainable consumption and production patterns worldwide. To be able to make a global change, we, the food consumers, must act responsibly, and start by making small changes in our own daily dietary pattern towards a more sustainable one. A sustainable diet is based on the equilibrium between the environment, society, and economics. This means that sustainable diet does not only satisfy our hunger, but also is economically sound, environmentally friendly, and culturally acceptable, while contributes to our food and nutrition security which ensures a healthy life for us and the generations to come.

Reducing food loss and waste (FLW) is an essential step towards attaining the sustainable diet. The amount of FLW being generated is partly associated with our nutritional behavior and the choices we make for our daily diet. The FLW has been not only a tremendous burden on the environment but also causes a huge loss of financial resources and has negative health and social effects. The agriculture sector is considered to have a major negative impact on the environment. That means a high level of FLW reflects a huge part of the agricultural practices being carried out without reaching the desired results; and, hence causing enormous unnecessary environmental harm. Besides, waste management also leads to considerable greenhouse gas emission and land degradation. Economically speaking, all these practices require tremendous financial resource usage and energy consumption. Moreover, from the social perspective, not only inconsiderate FLW creation is morally unacceptable, but also it hazards public health and social welfare.

According to FAO, about a third of the produced food worldwide gets lost or wasted instead of being eaten or even used for other beneficial purposes. This amount equals to 1.3 billion tons of food every year, which is enough to feed as many as 2 billion people. Given that there are about 821 million who are suffering from chronic forms of undernutrition, the amount of food

being wasted is more than enough to end global hunger. Although it would be unrealistic to assume FLW can reach zero, the reported numbers are way above reasonable levels. To be able to find proper solutions for FLW reduction, urgent needs exist to establish valid homogenized methods for studying this phenomenon.

Recent years witnessed an increasing effort in investigating FLW. Several studies and national and international programs have been successful in quantifying FLW at the different stages of food supply chains. However, there is a lack of a holistic and systematic approach in investigating FLW along all stages of food products' lifecycle. Moreover, the possible impact of dietary patterns on FLW level via influencing the structure of the food supply chain seems to be overlooked.

Lifecycle assessment (LCA) has recently drawn a lot of attention as a useful tool for holistic investigation in research, policymaking and even industry. LCA has been implemented mainly for studying the impact of a specific phenomenon on the environment. The method has been used vastly in food production system analysis as well. However, the FLW has been either entirely neglected or considered scanty within LCA modeling. Besides, the databases which are often used for LCA lack comprehensive information on FLW. Therefore, it is necessary to gather more data on FLW throughout the whole lifecycle of different food items.

The results of such studies can offer the consumers a better perspective of the problem and increase their awareness on how their dietary choices play key roles in restructuring the food production and supply systems. Rethinking dietary behavior towards FLW reduction could contribute to achieving sustainable patterns by increasing food availability and security, and saving considerable material and financial resources, while significantly lowering the environmental destruction. However, consumers are not the only role-players in this reform. Serious modifications need to be made in agricultural production, processing and supply systems.

Appendix

Appendix 1. The questionnaire used in the 2nd Survey

Original Version in Farsi

کد مصاحبه

ساعت (۲۴:۰۰)	تاریخ (روز/ماه)	کد پرسشگر	بلاک	ناحیه

دانشگاه علوم پزشکی شیراز
دانشکده تغذیه و علوم غذایی
مرکز تحقیقات تغذیه و علوم غذایی

عنوان طرح پژوهشی: **یافتن راهکارهایی برای بهبود الگوی مصرف در جهت کاهش دورریز و ضایعات زنجیره تولید و عرضه گندم در استان فارس**

اطلاعات پرسشنامه

شرکت‌کننده مایل به ضبط صدا می‌باشد.	**بله** ☐	**خیر** ☐
شماره تماس شرکت کننده (فقط در صورت رضایت شرکت‌کننده)		**مایل نبودند** ☐
نشانی شرکت کننده (فقط در صورت رضایت شرکت‌کننده)		**مایل نبودند** ☐
منطقه		
بلاک		
نام پرسشگر		
تاریخ (روز/ماه/سال)		
ساعت (۲۴:۰۰)		
تعداد افراد خانوار		

کد مصاحبه

اطلاعات مربوط به مصرف نان گندم خانوار

انواع نان	محل تهیه	مقدار هربار خرید	مقدار هربار دورریز	طریقه مصرف
نان های سنتی				
لواش (بازاری)				
لواش ماشینی				
لواش بسته‌بندی				
سنگک				
سنگک ماشینی				
سنگک بسته‌بندی				
تافتون				
تافتون ماشینی				
بربری				
بربری بسته‌بندی				
نان‌های حجیم				
باگت				
باگت بسته‌بندی				
همبرگری				
همبرگری بسته‌بندی				
بروتشن (کوچک گرد)				
بروتشن بسته‌بندی				
ساندویچی				
ساندویچی بسته‌بندی				
تُست تازه				
تُست بسته بندی				
بربری ماشینی				
بربری ماشینی بسته‌بندی				
سایر موارد............				

محل تهیه	مقدار هربار خرید	مقدار هربار دورریز	طریقه مصرف
۱= نانوایی محلی	**تعداد ذکر شود**	**بر اساس واحدهای زیر ذکر شود**	۱= به طور کامل
۲= نانوایی زنجیره ای		کف دست برای سنتی‌ها و بربری ماشینی	۲= جدا کردن (دورریختن) بخشهایی (ذکر شود)
۳= سوپر مارکت محلی		برش ۷ سانتیمتری برای باگت، ساندویچی و بروتشن	۷۷= موارد دیگر (ذکر شود)
۴= هایپر مارکت زنجیره ای		نصف نان برای همبرگری	
		برش برای تست	
۵= خانه			
۷۷= موارد دیگر (ذکر شود)			

کد مصاحبه

روش معمول انتقال نانهای غیر بسته‌بندیی از محل تهیه به خانه: ۱= بدون پوشش ۴= با روکش پارچه‌ای بعد از هوادهی ۲= با روکش پارچه‌ای ۵= با روکش پلاستیکی بعد از هوا دهی ۳= با روکش پلاستیکی ۷۷= موارد دیگر	
روش نگهداری در خانه: ۱= فریزر ۴= دمای اتاق در کیسه ۲= یخچال ۵= دمای اتاق بین سفره ۳= دمای اتاق در پارچه ۷۷= موارد دیگر	
مدت زمان معمول نگهداری: ۱=۱ تا ۲ روز ۵= بیشتر از ۲ هفته ۲= ۳تا۴ روز ۶= بیشتر از ۱ ماه ۳= ۵تا۷ روز ۷۷= موارد دیگر .... ۴= ۷تا۱۴ روز	
مدیریت دورریز ۱= با زباله ها دور می ریزم ۴= خوراک حیوانات خانگی (چه حیوانی) ۲= جداگانه دور می ریزم (نان خشکی) ۵= خوراک حیوانات محلی ۳= در غذاهای دیگر مصرف می کنم ۷۷= موارد دیگر	

کد مصاحبه

بسامد خوراک

فقط جهت کد گذاری است	مواد غذایی	متوسط بار مصرف				مقدار مصرف در هر بار تعداد / واحدمصرف	ملاحضات
		روز	هفته	ماه	سال		
۱	نان لواش (بازاری)					......./ ۱ کف دست	
۲	نان سنگک					......./ ۱ کف دست	
۳	نان تافتون					......./ ۱ کف دست	
۴	نان بربری					......./ ۱ کف دست	
۵	باگت					......./ برش ۷ cm	
	همبرگری					......./ نصف	
	بروتشن (کوچک گرد)					......./ برش ۷ cm	
	ساندویچی					......./ برش ۷ cm	
	تُست					......./ برش (اسلایس)	
۶	نان های سبوس دار(قهوه ای،جو)					......./ ۱ کف دست	
۷	برنج پخته					......./ ۱ کفگیر	
۸	ماکارونی پخته					......./ ۱ کفگیر	
۹	ورمیشل پخته					......./ ۱ لیوان	
۱۰	رشته					......./ ۱ لیوان	
۱۱	آرد گندم					......./ ۱ استکان شستی	
۱۲	جو پخته					......./ ۱ ق.غ	

کد مصاحبه

۱۳	بلغور پخته					......./ ۱ ق.غ	
۱۴	لپه					......./ ۱ ق.غ	
۱۵	عدس					......./ ۱ ق.غ عدس پلو ..../ ۱ ق.غ عدسی/آش	
۱۶	انواع لوبیا (سفید،قرمز،چیتی)					......./ ۱ ق.غ	
۱۷	نخود					......./ ۱ ق.غ	
۱۸	ماش					......./ ۱ ق.غ	
۱۹	گوشت چرخ‌کرده					......./ ۳ ق.غ/۳۰ گرم	
۲۰	گوشت خورشی (گاو، گوساله یا گوسفند)					......./ ۱ تکه خورشی	
۲۱	کنجاله سویا					......./ ۲ ق.غ/۳۰ گرم	
۲۲	همبرگر آماده					......./ ۱ عدد	
۲۳	مرغ					......./ ران کامل ..../ سینه کامل ..../ بال ..../ سایر	☐ با پوست ☐ بدون پوست ☐ با پوست ☐ بدون پوست ☐ با پوست ☐ بدون پوست ☐ با پوست ☐ بدون پوست
۲۴	کنسرو تن ماهی					......./ ۱/۲ قوطی/۴ ق.غ	
۲۵	ماهی (غیر از کنسرو تن) با ذکر نوع					......./ کف دست	
۲۶	سوسیس					......./ ۱ عدد	☐ آلمانی ☐ کوکتل
۲۷	کالباس					......./ ۱ برش	
۲۸	دل و جگر و قلوه					......./ ۱ تکه متوسط	
۲۹	سیرابی و شیردان					......./ ۱ قطعه	
۳۰	کله					......./ ۱ عدد کامل	

کد مصاحبه

۳۱	پاچه					......./ ۱ عدد کامل	
۳۲	زبان (گوسفند یا گاو)					......./ ۱ عدد کامل	☐ خوراک ☐ در کله پاچه
۳۳	مغز					......./ ۱ عدد کامل	
۳۴	تخم مرغ					......./ ۱ عدد (نیمرو) ..../ ۱ عدد (آبپز) ..../ ۱ عدد (داخل غذا)	
۳۵	شیر					......./ ۱ لیوان	☐بدون چربی یا کم چرب (<۲٪) ☐معمولی ☐ پرچرب (>۲٪) ☐شیر کاکائو ☐ شیر شکلاتی ☐ سایر ....
۳۶	پنیر (با ذکر نوع)					......./ ۱ قوطی کبریت	
۳۷	ماست					......./ ۱ کاسه ماست‌خوری	☐ معمولی ☐ چکیده ☐ پرچرب ☐ خامه ای
۳۸	خامه / سر شیر					......./ ۱ ق.غ	
۳۹	کره					......./ ۱ قوطی کبریت	☐داخل غذا ☐خارج غذا ☐هر دو
۴۰	مارگارین (کره گیاهی)					......./ ۱ قوطی کبریت	☐داخل غذا ☐خارج غذا ☐هر دو
۴۱	کشک					......./ ۱ ق.غ	
۴۲	خیار					......./ ۱ عدد متوسط	☐داخل سالاد ☐ به صورت تنها
۴۳	گوجه فرنگی					......./ ۱ عدد متوسط(خام) ..../ ۱ عدد متوسط(پخته)	
۴۴	کاهو خرد شده					......./ نصف لیوان	
۴۵	سبزی خوردن					......./ ۱ پیش دستی	
۴۶	سبزی خورشی (پخته)					......./ نصف ایوان	
۴۷	سبزی آش/ کوکو/ پلو					......./ ۱ لیوان	
۴۸	کدو خورشی/ بادمجان					......./ ۱ عدد متوسط	

کد مصاحبه

۴۹	سیب‌زمینی سرخ‌کرده					......./ ۱۰ خلال متوسط	
۵۰	سیب زمینی					......./ ۱ عدد متوسط	
۵۱	کرفس پخته					......./ نصف لیوان	
	کرفس خام						
۵۲	لوبیا سبز پخته					......./ نصف لیوان	
۵۳	هویج					......./ ۱ عدد متوسط	
۵۴	سیر خام					......./ ۱ حبه	
۵۵	پیاز خام					......./ ۱ عدد متوسط	
۵۶	پیاز سرخ کرده					......./ ۱ ق.غ	
۵۷	کلم (سفید و قرمز)					......./ ۱ کاسه ماست خوری	
۵۸	سایر انواع کلم (بروکلی، قمری، گل‌کلم)					......./ ۱ کاسه ماست خوری	
۵۹	فلفل دلمه‌ای					......./ ۱ عدد متوسط	
۶۰	اسفناج پخته					......./ نصف لیوان	
۶۱	شلغم (درفصل)					......./ ۱ عدد متوسط	
۶۲	قارچ پخته					......./ نصف لیوان	
۶۳	کدو حلوایی					......./ قطعه ۶×۶	
۶۴	فلفل تند/ شیرین					......./ ۱ عدد متوسط	
۶۵	نخود سبز پخته					......./ نصف لیوان	
۶۶	رب گوجه فرنگی					......./ ۱ ق.غ	

کد مصاحبه

۶۷	ترشی					.... / ۱ ق.غ / پیاله ترشی‌خوری	
۶۸	شور					.... / ۱ ق.غ / پیاله ترشی‌خوری	
۶۹	خیارشور					.... / ۱ عدد متوسط	
۷۰	زیتون سبز					.... / ۱۰ عدد متوسط	
۷۱	سیب					.... / ۱ عدد متوسط	
۷۲	موز					.... / ۱ عدد متوسط	
۷۳	گوجه سبز (در فصل)					.... / ۱ عدد متوسط	
۷۴	توت فرنگی (در فصل)					.... / ۳ عدد متوسط	
۷۵	توت سفید (در فصل)					.... / ۱۰ عدد متوسط	
۷۶	گیلاس / آلبالو (در فصل)					.... / ۱۰ عدد متوسط	
۷۷	زردآلو (در فصل)					.... / ۱ عدد متوسط	
۷۸	آلو (زرد و قرمز) (در فصل)					.... / ۱ عدد متوسط	
۷۹	هلو / شلیل (در فصل)					.... / ۱ عدد متوسط	
۸۰	انجیر تازه (در فصل)					.... / ۱ عدد متوسط	
۸۱	گلابی (در فصل)					.... / ۱ عدد متوسط	
۸۲	انگور (در فصل)					.... / ۱ خوشه کوچک	
۸۳	هندوانه (در فصل)					.... / ۱ قاچ متوسط	
۸۴	طالبی / گرمک (در فصل)					.... / ۱/۴ طالبی/گرمک متوسط	
۸۵	خربزه (در فصل)					.... / ۱ قاچ متوسط	

کد مصاحبه

۸۶	خرمالو (در فصل)					.... / ۱ عدد متوسط	
۸۷	انار (در فصل)					.... / ۱ عدد متوسط	
۸۸	نارنگی (در فصل)					.... / ۱ عدد متوسط	
۸۹	پرتقال (در فصل)					.... / ۱ عدد متوسط	
۹۰	لیمو شیرین (در فصل)					.... / ۱ عدد متوسط	
	لیمو ترش (در فصل)					.... / ۱ عدد متوسط	
	گریپ فروت (در فصل)					.... / ۱ عدد متوسط	
۹۱	کیوی					.... / ۱ عدد متوسط	
۹۲	سایر میوه ها (آناناس ، زغال اخته)					.... / ۱ عدد متوسط	
۹۳	آب مرکبات (با ذکر نوع)					.... / ۱ لیوان	
۹۴	آب میوه و سبزی طبیعی (سیب، طالبی، هویج و...)					.... / ۱ لیوان	
۹۵	خرما					.... / ۱ عدد متوسط	
۹۶	توت خشک					.... / ۲۰ عدد	
۹۷	کشمش					.... / ۱ ق.غ	
۹۸	سایر خشکبار با ذکر نوع (انجیر خشک، انواع برگه، آلبالو خشک)					.... / ۱۰ عدد متوسط	
۹۹	روغن نباتی جامد					.... / ۱ ق.غ	
۱۰۰	روغن مایع					.... / ۱ ق.غ	☐آفتاب گردان☐ذرت ☐سویا ☐کنجد
۱۰۱	پیه/ دنبه					.... / ۱ تکه متوسط	
۱۰۲	روغن حیوانی					.... / ۱ ق.غ	

کد مصاحبه

۱۰۳	روغن زیتون					......./ ۱ ق.غ	
۱۰۴	سس مایونز/ سسهای سفید					......./ ۱ ق.غ	
۱۰۵	گردو					......./ ۱ عدد مغز کامل	
۱۰۶	بادام زمینی					......./ ۲۰ عدد مغز	
۱۰۷	بادام					......./ ۱۰ عدد مغز	
۱۰۸	پسته					......./ ۱۰ عدد	
۱۰۹	تخمه (کدو،آفتاب گردان،هندوانه)					......./ ۱ کاسه ماست خوری	
۱۱۰	انواع بیسکویت (با ذکر نوع و اندازه)					......./ عدد	□ انواع شیرین □ انواع شور
۱۱۱	کیک/کلوچه صنعتی					......./ ۱ عدد/ بسته	
۱۱۲	شیرینی خشک					......./ ۱ عدد متوسط	
۱۱۳	شیرینی تر					......./ ۱ عدد متوسط	
۱۱۴	چای					......./ ۱ لیوان	
۱۱۵	حلوا شکری					......./ ۱/۴ عدد/ ۱ قوطی کبریت	
۱۱۶	قند / شکر پنیر					......./ ۱۰ حبه	
۱۱۷	شکر					......./ ۱ ق.م	
۱۱۸	عسل/ مربا					......./ ۱ق.م	
۱۱۹	آبنبات					......./ عدد	
۱۲۰	نبات					......./ ۱ تکه متوسط	
۱۲۱	تافی					......./ ۱ عدد	

کد مصاحبه

۱۲۲	گز						آردی لقمه ای
۱۲۳	سوهان					......./ ۱ قطعه	
۱۲۴	نقل					......./ ۱۰ عدد	
۱۲۵	شکلات/کاکائو با ذکر نوع					......./ ۱ عدد	
۱۲۶	قهوه/ نسکافه					......./ ۱ لیوان	
۱۲۷	پفک					......./ ۱ بسته	(اگر به عدد ذکر شود یادداشت گردد)
۱۲۸	چیپس					......./ ۱ بسته	(اگر به تعداد حلقه ذکر شود یادداشت گردد)
۱۲۹	بستنی					......./ نصف لیوان/ ۱عدد	سنتی غیرسنتی
۱۳۰	نوشابه‌های گازدار					......./ ۱ لیوان/ ۱ شیشه	رژیمی معمول
۱۳۱	آبمیوه صنعتی					......./ ۱ بسته/ لیوان	
۱۳۲	دوغ					......./ ۱ لیوان	
۱۳۳	نمک					......./ ۱ق.غ برای تهیه غذا ..../ ۱ ق.غ اضافه شده به غیر از غذا	ید دار غیر ید دار
۱۳۴	آبلیمو/ سرکه/ آبغوره					......./ ۱ ق.غ	
۱۳۵	خورش (هرنوع)						
۱۳۶	آبگوشت (هر نوع)						
۱۳۷	آش (هر نوع)						
۱۳۸	پیتزا						
۱۳۹	سالاد سبزیجات						

کد مصاحبه

اطلاعات اجتماعی و اقتصادی خانوار

سرپرست خانوار	مسئول تغذیه ۲	فرد مصاحبه شونده	عضو خانوار ↓ شروع	تاریخ تولد (سال/ماه) (سال/ماه/روز > ۲ سال) ۳	سطح تحصیلات (فقط بالای ۱۸ سال)	مدرسه میرود؟ (فقط زیر ۱۸ سال)	شغل (فقط بالای ۱۸ سال) ۴	کار میکند؟ (فقط زیر ۱۸ سال)	وضعیت تأهل	مشکل سلامتی ۵
			۱= مادر		۱= بی سواد	+ = بله	۱= بی کار	+ = بله	۱= متأهل	۰= ندارد
			۲= پدر		۲= نهضت و ابتدایی	- = خیر	۲= خانه دار	- = خیر	۲= مجرد	نوشته شده = دارد
			۳= خواهر		۳= راهنمایی و سیکل		۳= محصل، دانشجو		۳= مطلقه	
			۴= برادر		۴= متوسطه و دیپلم		۴= دانشجو حقوق-بگیر		۴= فوت همسر	
			۷۷=موارد دیگر		۵= کاردانی و کارشناسی		۵= بازنشسته		۷۷=موارد دیگر	
					۶= کارشناسی ارشد و بالاتر		۶= کاگر، کشاورز، راننده			
					۷۷=موارد دیگر		۷= کارمند، معلم، نظامي، شاغل مستقل			
							۸= مدیر یا رئیس کارخانه یا اداره دولتي، کارفرما، پزشك، دندانپزشك، استاد دانشگاه و مغازه‌دار			
							۷۷=موارد دیگر			

کد مصاحبه

وضعیت اقتصادی

۱	**درآمد ماهیانه خانوار به تومان** ۱ = زیر ۵۰۰ هزار ۴ = ۲ تا ۳ میلیون ۷ = ۵ تا ۶ میلیون ۲ = ۵۰۰ هزار تا ۱ میلیون ۵ = ۳ تا ۴ میلیون ۸ = ۶ تا ۷ میلیون ۳ = ۱ تا ۲ میلیون ۶ = ۴ تا ۵ میلیون ۹ = بالای ۷ میلیون	
۲	**نوع ملک:** ۱ = ملکی ۲ = اجاره‌ای ۷۷ = موارد دیگر	
۳	**متراژ منزل**	
۴	**تعداد اتاق (غیر از آشپزخانه و سرویس‌های بهداشتی)**	

چند عدد / کدامیک از لوازم زیر در منزل وجود دارد؟

۵	**خودرو**	
۶	**کامپیوتر / لپ‌تاپ**	
۷	**تلفن هوشمند/ تبلت**	
۸	**ماشین لباسشویی** – = ناموجود ۱ = اتوماتیک ۲ = سطلی	
۹	**مودم اینترنت** + = موجود – = ناموجود	
۱۰	**تلویزیون LED/LCD** + = موجود – = ناموجود	
۱۱	**ماکروویو/آون/فر توکار/فر** + = موجود – = ناموجود	
۱۲	**فریزر جداگانه** + = موجود – = ناموجود	
۱۳	**یخچال سایدبای‌ساید** + = موجود – = ناموجود	
۱۴	**ماشین ظرفشویی** + = موجود – = ناموجود	
۱۵	**موتورسیکلت** + = موجود – = ناموجود	

English Translation of the Questionnaire

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

Shiraz University of Medical Sciences
School of Nutrition and Food Sciences
Nutrition and Food Science Research Center

Project title: Strategy development for improving consumption patterns to reduce loss and waste along the wheat bread supply chains in Fars province

Questionnaire information

The participant consents to voice recording.	☐ Yes	☐ No
Phone (optional)		
Address (optional)		
Area		
Block		
Interviewer's name		
Date (YY/MM/DD)		
Time (24:00)		
Household size		

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

Household's bread consumption information

Bread type	Purchasing place	Bread amount typically purchased	Waste amount of a typical purchase	Consumption recipe
Traditional				
Lavash				
Machine-made lavash				
Packaged lavash				
Sangak				
MM Sangak				
P Sangak				
Taftoon				
MM taftoon				
Barbari				
P barbari				
Non-traditional				
Baguette				
P baguette				
Hamburger bun				
P hamburger bun				
Bread roll				
P bread roll				
Sandwich baguette				
P sandwich baguette				
Toast				
P toast				
MM barbari				
P MM barbari				
Others.....				
MM = machine-made P = packaged	1 = local bakery 2 = bakery chain shop 3 = local supermarket 4 = big-box store 5 = homemade 77 = others (note)	Note the unit numbers	**Note based on measurement scale** Hand palm for traditional and MM barbari A 7-centimeter cut for baguette, sandwich baguette, and bread roll Half of a piece for hamburger bun On slice for toast	1 = whole bread 2 = part(s) discard (note which part) 77 = others (note)

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

The typical way of carrying bread from the place of purchase to home 1 = no cover 4 = with a fabric cover after aerating 2 = with a fabric cover 5 = with a plastic cover after aerating 3 = with a plastic cover 77 = others	
Storage method at home 1 = in a freezer 4 = in room temperature with sealed plastic cover 2 = in a refrigrator 5 = in room temperature with open plastic cover 3 = in room temrature 77 = others	
Storage duration 1 = 1-2 days 5 = more than two weeks 2 = 3-4 days 6 = more than a month 3 = 5-7 days 77 = others .... 4 = 7-14 days	
Waste management 1 = disposed with residual waste 4 = domestic animal feed 2 = disposed with organic waste 5 = local animal feed 3 = resued in other meals 77 = others	

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

Food frequency questionnaire

Code	Food item	Average consumption frequency				Consumption amount Frequency | unit	Comment
		Day	Week	Month	Year		
1	Lavash bread					1 hand palm | …	
2	Sangak bread					1 hand palm | …	
3	Taftoon bread					1 hand palm | …	
4	Barbari bread					1 hand palm | …	
5	Baguette bread					7-cm cut | …	
	Hamburger bun					Half | …	
	Bread roll					7-cm cut | …	
	Sandwich baguette					7-cm cut | …	
	Toast bread					1 slice | …	
6	Whole grain bread (e.g., barley)					1 hand palm | …	
7	Cooked rice					1 skimmer | …	
8	Cooked pasta/spaghetti					1 skimmer | …	
9	Cooked noodles/vermicelli					1 cup (250 ml) | …	
10	Iranian noodles (Reshte)					1 cup (250 ml) | …	
11	Wheat flour					⅗ cup (150ml) | …	
12	Cooked barely					1 tbsp. | …	
13	Oatmeal					1 tbsp. | …	
14	Split pea					1 tbsp. | …	

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

15	Lentil					Adas polow (mixed with rice): 1 tbsp. | … Adasi (lentil soup): 1 tbsp. | …	
16	Beans					1 tbsp. | …	
17	Chickpea					1 tbsp. | …	
18	Mung bean					1 tbsp. | …	
19	Minced meat					30 gr or 3 tbsp. | …	
20	Goulash meat (lamb, beef, veal)					1 goulash cube | …	
21	Soybean meal					30 gr or 2 tbsp. | …	
22	Hamburger					1 unit | …	
23	Chicken					1 leg | … 1 breast | … 1 wing | … Others | …	□ with skin □ skinless □ with skin □ skinless □ with skin □ skinless □ with skin □ skinless
24	Tuna fish can					½ can or 4 tbsp. | …	
25	Fish (note the type)					1 hand palm | …	
26	Sausages					1 unit | …	Type: …..
27	Sausages (cold cuts)					1 slice | …	
28	Sheep heart, liver, kidney					1 medium unit | …	
29	Sheep's tripe					1 piece | …	
30	Sheep's head					1 unit | …	
31	Sheep's feet					1 unit | …	

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

32	Tongue (sheep/veal)					1 unit | …	☐ with head and trotters ☐ separately
33	Sheep's brain					1 unit | …	
34	Egg					1 scrambled or fried | … 1 boiled | … 1 mixed in food | …	
35	Milk					1 cup (250 ml) | …	☐ no/low fat (<2%) ☐ normal ☐ high fat (>2%) ☐ chocolate milk ☐ others …
36	Cheese (note the type)					1 match box | …	
37	Yogurt					1 bowl (246 ml) | …	☐ normal ☐ concentrated ☐ high-fat ☐ creamy
38	Cream					1 tbsp. | …	
39	Butter					1 match box | …	☐ with food ☐ separately ☐ both
40	Margarine					1 match box | …	☐ with food ☐ separately ☐ both
41	Kashk					1 tbsp. | …	
42	Cucumber					1 medium unit | …	☐ in salad ☐ separately
43	Tomato					Cooked: 1 medium unit | … Raw: 1 medium unit | …	
44	Chopped lettuce					½ cup (125 ml) | …	
45	Herbs					1 16-cm plate | …	
46	Cooked herbs					½ cup (125 ml) | …	
47	Cooked herbs mixed in food (kookoo, pottage, and rice)					1 cup (250 ml) | …	
48	Zucchini/eggplant					1 medium unit | …	

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

49	Fried potatoes					10 medium sticks | …	
50	Potato					1 medium unit | …	
51	Cooked celery					½ cup (125 ml) | …	
	Raw celery					½ cup (125 ml) | …	
52	Cooked green beans					½ cup (125 ml) | …	
53	Carrot					1 medium unit | …	
54	Raw garlic					1 clove | …	
55	Raw onion					1 medium unit | …	
56	Fried onion					1 tbsp. | …	
57	Red and white cabbage					1 bowl (246 ml) | …	
58	Other kinds of cabbage					1 bowl (246 ml) | …	
59	Bell pepper					1 medium unit | …	
60	Cooked spinach					½ cup (125 ml) | …	
61	Turnip (seasonal)					1 medium unit | …	
62	Cooked mushrooms					½ cup (125 ml) | …	
63	Pumpkin					6×6 cm piece | …	
64	Chili pepper					1 medium unit | …	
65	Cooked green pea					½ cup (125 ml) | …	
66	Tomato paste					1 tbsp. | …	

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

67	Pickles					1 tbsp. | …	
68	Salted vegetables					1 tbsp. | …	
69	Cucumber pickles					1 medium unit | …	
70	Olive					10 medium unit | …	
71	Apple					1 medium unit | …	
72	Banana					1 medium unit | …	
73	Greengage (seasonal)					1 medium unit | …	
74	Strawberry (seasonal)					3 medium unit | …	
75	Mulberry (seasonal)					10 medium unit | …	
76	Cherries (seasonal)					10 medium unit | …	
77	Apricot (seasonal)					1 medium unit | …	
78	Plum (seasonal)					1 medium unit | …	
79	Peach/nectar (seasonal)					1 medium unit | …	
80	Fresh fig(seasonal)					1 medium unit | …	
81	Pear (seasonal)					1 medium unit | …	
82	Grapes (seasonal)					1 small bunch | …	
83	Watermelon (seasonal)					1 medium slice | …	
84	Cantaloupe/melon (seasonal)					¼ medium unit | …	
85	Persian melon (seasonal)					1 medium slice | …	

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

86	Persimmon (seasonal)					1 medium unit | …	
87	Pomegranate (seasonal)					1 medium unit | …	
88	Tangerine (seasonal)					1 medium unit | …	
89	Orange (seasonal)					1 medium unit | …	
90	Sweet lemon (seasonal)					1 medium unit | …	
	Lime (seasonal)					1 medium unit | …	
	Grapefruit (seasonal)					1 medium unit | …	
91	Kiwi					1 medium unit | …	
92	Other fruits (pineapple, dogberry)					1 medium unit | …	
93	Citrus juice					1 cup (250 ml) | …	Type: …
94	Fresh fruits and vegetable juice					1 cup (250 ml) | …	
95	Dates					1 medium unit | …	
96	Dried mulberry					20 pieces | …	
97	Raisin					1 tbsp. | …	
98	Others (dried fig, follicle, etc.)					10 pieces | …	
99	Vegetable hydrogenated fat					1 tbsp. | …	
100	Oil					1 tbsp. | …	☐ soybean ☐ sunflower ☐ corn ☐ sesame
101	Tallow					1 medium cube cut | …	
102	Animal fat					1 tbsp. | …	

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

103	Olive oil					1 tbsp. | …	
104	Mayonnaise					1 tbsp. | …	
105	Walnuts					1 whole kernel | …	
106	Peanut					20 pieces | …	
107	Almond					10 pieces | …	
108	Pistachio					10 pieces | …	
109	Seeds (pumpkin, sunflower, watermelon)					1 bowl (246 ml) | …	
110	Biscuits					1 piece | …	□ salty □ sweet
111	Industrial cakes					1 piece or pack | …	
112	Pastries (non-crème)					1 medium unit | …	
113	Pastries (creamy)					1 medium unit | …	
114	Tea					1 cup (250 ml) | …	
115	Sesame paste					¼ piece or 1 match box | …	
116	Cube sugar/shekar panir					10 cubes | …	
117	Sugar					1 tsp. | …	
118	Honey/jam					1 tsp. | …	
119	Candy					1 unit | …	
120	Sugar candy					1 medium unit | …	
121	Toffy					1 unit | …	

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

122	Gaz						Type: …
123	Sohan					1 unit | …	
124	Noghl					10 unit | …	
125	Chocolate					1 unit | …	Type: …
126	Coffee					1 cup (250 ml) | …	
127	Puffs					1 pack | …	(note if consumed in pieces)
128	Potato chips					1 pack | …	(note if consumed in pieces)
129	Ice cream					½ cup (125 ml) or 1 unit | …	□ traditional □ non-traditional
130	Soft drinks					1 cup (250 ml) | …	□ diet □ normal
131	Industrial fruit juice					1 cup or pack (250 ml) | …	
132	Doogh					1 cup (250 ml) | …	
133	Salt					1 tbsp. in food | … 1 tbsp. in separately | …	□ ionized □ normal
133	Lemon juice/vinegar/verjuice					1 tbsp. | …	
134	Stew						
135	Broth						
136	Pottage						
137	Pizza						
138	Green salad						

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

Socioeconomic information

2 Start ↓ 3 4 5

Head of household	Responsible for nutrition	Intervewee	Member	Date of birth (YY/MM) For children < 2 (YY/MM/DD)	Education (for +18)	School? (for -18)	Occupation (for +18)	Do they work? (for-18)	Marital status	Diet-related illness
			1 = mother		1 = illiterate	+ = yes	1 = unemployed	+ = yes	1 = married	0 = no illness
			2 = father		2 = primary school	- = no	2 = housekeeper	- = no	2 = single	Nothe others
			3 = sister		3 = middle school		3 = student		3 = divorced	
			4 = brother		4 = high school		4 = paid student		4 = widowed	
			Note others		5 = bachlor's		5 = retired		Nothe others	
					6 = master's/higher		6 = worker, farmer, driver			
					Nothe others		7 = teacher, employee, freelancer, Army			
							8 = executive, medical doctor, professor, business owner			
							Nothe others			

Interview Code

Area	Block	Interviewer code	Date (month/day)	Time (24:00)

Income and housing information

1	Household's monthly total income 1 = <500 k tomans; 2 = 500 k – 1 million tomans; 3 = 1 – 2 million tomans; 4 = 2 – 3 million tomans; 5= 3 – 4 million tomans; 6 = 4 – 5 million tomans; 7 = 5 – 6 million tomans; 8 = 6 – 7 million tomans; 9 = >7 million tomans	
2	Housing situation 1 = owned 2 = leased Note others	
3	House size	
4	Room numbers (excluding kitchen, bathroom, and toilet)	

Asset ownership

5	How many cars?		
6	How many computers/laptops?		
7	How many smartphones/tablets?		
8	Wash machine	- = not owned + = owned	
9	Home internet	- = not owned + = owned	
10	LED/LCD TV	- = not owned + = owned	
11	(Microwave) oven	- = not owned + = owned	
12	Separate freezer	- = not owned + = owned	
13	Side-by-side refrigerator	- = not owned + = owned	
14	Dishwasher	- = not owned + = owned	
15	Motorcycle	- = not owned + = owned	

Acknowledgement

I feel incredibly fortunate and grateful that my journey has been enriched by the presence of numerous remarkable individuals who have provided unwavering support and encouragement. The list of people I need to thank is extensive, and I am truly grateful to have had such an incredible network of individuals who believed in me and supported me throughout this endeavor.

First and foremost, I would like to express my sincere gratitude to my advisor, Prof. Dr. Reiner Doluschitz, for accepting me as his student and for his support and invaluable guidance. His solid experience, patience, flexibility, and constructive feedback have been crucial in shaping the direction of this research and improving the quality of my work.

I am deeply grateful to the Food Security Center of the University of Hohenheim for granting me the scholarship that has supported me throughout my doctoral journey. In particular, I want to extend my deepest appreciation to Dr. Nicole Schönleber, Dr. Heinrich Hagel, and Dr. Jenny Kopsch-Xhema for their belief in me, as well as their continuous support and motivation. Their encouragement and guidance have been invaluable in shaping my research and providing me with the guidance to pursue my academic goals.

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Soleymanpour, Dr. Hossein Mahmoudi, Dr. Maryam Ranjbar, Dr. Alireza Yazdani, Dr. Matin Mohamadi, Mr. Soleymani, Mr. Vaselali, Dr. Nasrollah Erfani, and Dr. Mojtaba Heydari. I apologize if I have unintentionally missed anyone's name. Your support, collaboration, and contributions have been invaluable, and I am deeply grateful for the friendship and camaraderie we have shared throughout this journey.

I extend my sincere appreciation to the Khosravizadeh Foundation for their generous financial support, enabling me to pursue my master's degree in Germany in 2012. This support not only facilitated my educational pursuits but also significantly contributed to the successful completion of my doctoral dissertation. I am truly grateful for their belief in my potential and their instrumental role in shaping my academic path.

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Curriculum Vitae

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Education

2017 – Present	**Doctoral Student in Global Food Security** Universiy of Hohenheim, Stuttgart, Germany
2012 – 2016	**Master of Science in Organic Agriculture and Food Systems** University Hohenheim, Stuttgart, Germany
2006 – 2011	**Bachelor of Science in Agricultural Engineering** Shiraz University, Shiraz, Iran

Work experiance

11/2022 – Present	Research Associate within the project "DIWAN" at the Institute of Farm Management (410b), University of Hohenheim
12.2021 - Present	Scientific Staff (Public & Media Relations), Inst. of Farm Management (410b), University of Hohenheim
11.2012 - Present	IT Administrator, Inst. of Societal Transition & Agriculture, University of Hohenheim
02.2020 – 11.2021	Webmaster, Dep. of Agricultural Management, University of Hohenheim
10.2015 – 12.2019	Webmaster & Social Media Manager, Food Security Center, University of Hohenheim
10.2015 – 03.2016	Research Assistant, Inst. of Biological Chemistry & Nutritional Science, University of Hohenheim
08.2015 – 03.2016	Research Assistant, Inst. of Societal Transition & Agriculture, University of Hohenheim
04.2014 – 09.2014 *&* *04.2015 – 09.2015*	Teaching Assistant, Inst. of Biological Chemistry & Nutritional Science, University of Hohenheim
08.2014 – 07.2015	Research Assistant, Inst. of Animal Breeding in the Tropics & Subtropics, University of Hohenheim
01.2014 – 03.2015	Research Assistant, Inst. of Gender & Nutrition, University of Hohenheim
02.2014 – 09.2014	Teaching Assistant, Inst. of Gender & Nutrition, University of Hohenheim

03.2014 – 06.2014	Lab Technician, Inst. of Plant breeding, University of Hohenheim
03.2013 – 02.2014	Research Assistant, Inst. of Crop Biodiversity & Breeding Informatics, University of Hohenheim
10.2009 – 05.2010	Research Assistant, Inst. of Animal Sciences, Shiraz University

Additioanl Skills

Languages
- Persian *(native)*
- English *(excellent command)*
- German *(upper intermediate "B2.1")*
- Arabic *(beginner)*

Scientific skills
- Quantitative research
- Qualitative research
- Multiple Regression modelling
- Academic writing
- Experimental design
- Survey Design
- Questionnaire design
- Dietary pattern analysis
- Anthropometric assessment
- Biochemical analysis of food
- Biophysical analysis of food
- Sensory analysis of food
- HPLC
- Flow cytometry

Computer skills
- SPSS
- MAXQDA
- R
- SAS
- C
- HTML
- Typo3
- MS Office

Hobbies
- Music
- Karate
- Swimming
- Yoga
- Carpentry
- Photography

Stuttgart, 15.06.2023

Affidavit

Annex 3

Declaration in lieu of an oath on independent work

according to Sec. 18(3) sentence 5 of the University of Hohenheim's Doctoral Regulations for the Faculties of Agricultural Sciences, Natural Sciences, and Business, Economics and Social Sciences

1. The dissertation submitted on the topic

Understanding and Addressing Food Loss and Waste: A Multidimensional Analysis of Wheat Loss and Bread Waste in Iran

is work done independently by me.

2. I only used the sources and aids listed and did not make use of any impermissible assistance from third parties. In particular, I marked all content taken word-for-word or paraphrased from other works.

3. I did not use the assistance of a commercial doctoral placement or advising agency.

4. I am aware of the importance of the declaration in lieu of oath and the criminal consequences of false or incomplete declarations in lieu of oath.

I confirm that the declaration above is correct. I declare in lieu of oath that I have declared only the truth to the best of my knowledge and have not omitted anything.

Stuttgart, 15.06.2023

Place, Date

Signature